Università
Ca' Foscari
Venezia

Master's Degree programme — Second Cycle
(D.M. 270/2004)
in Economics, Finance and Sustainability — Sustainable Finance

Final Thesis

–

Ca' Foscari
Dorsoduro 3246
30123 Venezia

Aviation Industry and Sustainability: Impact of Air Transport on Climate Change, Sustainability in Airlines and End-users' Awareness and Preferences

Supervisor
Ch. Prof. Francesco Scarpa

Assistant Supervisor
Ch. Prof. Silvia Panfilo

Candidate
Silvia Farinelli
Matriculation number 875592

Academic Year
2023/2024

Contents

Abstract 1

Introduction 3

1 Sustainability Background 5

1.1 Introducing Climate Change 7
1.2 History of Sustainability 9
1.3 Sustainable Development 14
1.4 Three Pillars of Sustainability 16
1.4.1 Economic Sustainability 18
1.4.2 Social Sustainability 18
1.4.3 Environmental Sustainability 18
1.5 Businesses & Sustainability: The Concept of Corporate Sustainability 19

2 Aviation Industry: Airlines and Sustainability 23

2.1 Introduction to Aviation Industry 24
2.1.1 Aviation Industry vs. Airlines 25
2.2 Air traffic and Environmental Concerns 26
2.2.1 The Impact on Climate change 27
2.2.2 Air quality 32
2.2.3 Noise pollution 34
2.3 Literature Review 36
2.4 Airlines and Sustainability Reporting 39
2.4.1 SASB Standards - Airlines Sustainability Accounting Standards 40
2.5 EU Taxonomy Regulation and Aviation 44
2.5.1 EU Taxonomy: an introduction 44
2.5.2 The Delegated Regulation (EU) 2023/2485 of 27 June 2023 48
2.6 Decarbonization Approaches in the Aviation Industry 53
2.6.1 Policy instruments 54
2.6.2 Sustainable Aviation Fuel (SAF) 64
2.6.3 New technologies: Fleet Renewal and Carbon Capture Technologies 67
2.6.4 Voluntary Carbon Offsets (VCO) 71
2.6.5 Enhanced Operational Efficiency and Infrastructure Improvements 73
2.6.6 Sustainable Cabin Practices 76

3 Airlines and Environmental Sustainability **79**
3.1 Low-cost Carriers: easyJet plc and Ryanair Holdings plc 79
3.1.1 easyJet plc 79
3.1.2 Ryanair Holdings plc 87
3.2 Legacy Airlines: Deutsche Lufthansa AG and KLM Dutch 94
3.2.1 Deutsche Lufthansa AG 94
3.2.2 KLM Royal Dutch Airlines 104
3.3 Airlines and Environmental Sustainability: Conclusions and Comparisons . . 115

4 Survey: Consumers' awareness of sustainability concerns when taking flights **119**
4.1 Methodology 119
4.1.1 Background 119
4.1.2 Target population 119
4.1.3 Timing 119
4.1.4 Objective 119
4.2 Results 121
4.2.1 Summary statistics 121
4.2.2 Demographic questions 121
4.2.3 Survey-specific questions 126
4.2.4 Chi-squared (χ^2) test 137
4.3 Conclusions on the survey 175

5 Conclusions **179**

Appendix Questions **185**
Appendix Demographic questions 185
Appendix Survey-specific questions 186

References **190**

List of Figures

1 Earth Overshoot Day from 1971 to 2023. As the Figure displays, the Earth Overshoot Day occurrence demonstrated a downward trend in the last decades, occurring earlier each year. Source: https://overshoot.footprintnetwork.org/. 6

2 Change in the observed warming in global surface temperature between the two time periods, from 1850–1900 to 2010-2019. (Source: IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change) 8

3 Change in the level of warming induced by mixed-greenhouse gas emissions, human activity, and natural sources of warming (e.g., solar and volcanic activities) in the period 2010-2019 from 1850–1900. The results exhibit severe increases in both atmospheric concentrations of several GHGs and total anthropogenic warming. (Source: IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change) 9

4 The 17 Sustainable Development Goals (Source: UN Sustainable Development Goals website). 16

5 The sustainability pillars: social, environmental and economic. 17

6 Non-Financial Reporting Directive double materiality perspective when reporting climate-related information. (Source: Guidelines on non-financial reporting: Supplement on reporting climate-related information (2019/C 209/01), European Commission) 20

7 Number of scheduled passengers boarded by the global airline industry, in millions (2004-2022). (Source: statista.com) 26

8 Direct CO_2 emissions from fossil jet kerosene combustion in aviation (international and domestic aviation) in the Net Zero Scenario, 2000-2030 (Source: International Energy Agency (2022), World Energy Outlook 2022, IEA, CO_2 emissions in aviation in the Net Zero Scenario, 2000-2030). 28

9 Schematic representation of air traffic climate impacts. Adapted by (Source: Fichert, F., Forsyth, P., & Niemeier, H. M. (2020). Aviation and Climate Change. Abingdon: Routledge). 29

10 CO_2 emissions (in million metric tons) from worldwide commercial aviation 2004-2022. (Source: statista.com) 30

11 Estimated Contribution of Measures For Reducing International Aviation Net CO_2 emissions. (Source: ICAO website) 61
12 World map showing the States participating voluntarily in the CORSIA scheme as of 2023 (in green); the application will then be extended mandatorily to all States (in blue) from 2027 (second phase), excluding "small islands, least developed countries, land-locked developed countries and states having less than 0.5% of air traffic" (in yellow). (Source: CORSIA Fact sheet, 2023) . . 63
13 Contribution of sustainable aviation fuel (SAF) to the achievement of the overarching goal of the ICAO's net zero CO_2 by 2050. IATA foresees the increasing deployment of SAF as the sustainability measure with the highest efficiency potential to permit the achievement of the decarbonization goal. (Source: IATA, December 2023, "Net zero 2050: sustainable aviation fuels, Fact sheet") 65
14 The carbon lifecycle of the sustainable aviation fuel (SAF). (Source: IATA, 2023, What is SAF?) 66
15 Decarbonization of aviation by 2050 assuming Scenario 1, pushing technological and operational improvements. (Source: ATAG's Waypoint 2050, 2nd edition: September 2021) 68
16 Decarbonization of aviation by 2050 assuming Scenario 3, adopting a more aspirational and aggressive strategy from the technological perspective. (Source: ATAG's Waypoint 2050, 2nd edition: September 2021) 69
17 Contribution of operational and infrastructure refinements to the achievement of the overarching goal of the ICAO's net zero CO_2 by 2050. IATA foresees operational and infrastructure refinements would result in the least contributing sustainability measure to achieving the decarbonization goal. (Source: IATA, December 2023, "Net zero 2050: operational and infrastructure improvements - Fact sheet") 73
18 Ryanair Path to Net Zero. (Source: Ryanair Group Sustainability Report, 2023) 88
19 Respondents' classification according to their gender. 123
20 Respondents' classification according to the age bracket to which they belong. 124
21 Respondents' classification according to their education degree. 125
22 Respondents' classification according to their level of income. 126
23 Respondents' level of climate awareness regarding climate emergency and environmental impacts of air travel. 129
24 Air travel frequency of respondents. 130

25 Frequencies of the different amounts of the global share of energy-related CO_2 emissions for which respondents believe the aviation industry is responsible. . 131
26 Respondents' level of relevance attributed to each air travel environmental impact. 132
27 Respondents' willingness to pay when facing a low price difference between a flight ticket surcharged by a "green fare" (Ticket 1) and one without any fee (Ticket 2). 133
28 Respondents' willingness to pay when facing a high price difference between a flight ticket surcharged by a "green fare" proposed by an airline adopting VCOs (Ticket 1 from Airline company A) and one without any fee proposed by an airline not implementing VCOs in its sustainability strategy (Ticket 2 from Airline company B). 134
29 Respondents' beliefs concerning environmental concerns and corporate sustainability efforts undertaken by airlines. 135
30 Most effective decarbonization strategies in the aviation industry according to respondents. 136
31 Absolute frequencies of the variables "climate awareness" and "gender". . . . 137
32 Absolute frequencies of the variables "climate awareness" and "age". 139
33 Absolute frequencies of the variables "climate awareness" and "education". . 141
34 Absolute frequencies of the variables "climate awareness" and "air travel environmental impact awareness". 143
35 Absolute frequencies of the variables "air travel environmental impact awareness" and "air travel frequency". 145
36 Absolute frequencies of the variables "income" and "willingness to pay (low price difference)". 147
37 Absolute frequencies of the variables "income" and "willingness to pay (high price difference, different airlines)". 149
38 Absolute frequencies of the variables "gender" and "willingness to pay (low price difference)". 151
39 Absolute frequencies of the variables "gender" and "willingness to pay (high price difference, different airlines)". 152
40 Absolute frequencies of the variables "age" and "willingness to pay (low price difference)". 154
41 Absolute frequencies of the variables "age" and "willingness to pay (high price difference, different airlines)". 156

42 Absolute frequencies of the variables ”education” and ”willingness to pay (low price difference)”. 158
43 Absolute frequencies of the variables ”education” and ”willingness to pay (high price difference, different airlines)”. 160
44 Absolute frequencies of the variables ”air travel frequency” and ”willingness to pay (low price difference)”. 162
45 Absolute frequencies of the variables ”air travel frequency” and ”willingness to pay (high price difference, different airlines)”. 164
46 Absolute frequencies of the variables ”climate awareness” and ”willingness to pay (low price difference)”. 166
47 Absolute frequencies of the variables ”climate awareness” and ”willingness to pay (high price difference, different airlines)”. 168
48 Absolute frequencies of the variables ”air travel environmental impact awareness” and ”relevance of air travel impact on climate change”. 170
49 Absolute frequencies of the variables ”air travel environmental impact awareness” and ”relevance of air travel impact on air quality”. 172
50 Absolute frequencies of the variables ”air travel environmental impact awareness” and ”relevance of air travel impact on noise pollution”. 174

List of Tables

1 Sustainability Disclosure Topics & Metrics. (Source: Sustainability Accounting Standards - Airlines, sasb.org) . . . 43
2 Activity Metrics. (Source: Sustainability Accounting Standards - Airlines, sasb.org) . . . 44
3 easyJet plc's aircraft in fleet: comparison between FY2023 and FY2022. (Source: easyJet plc's Annual Report and Accounts, FY2023 and FY2022) . . . 80
4 SASB Sustainability Disclosure Topics & Accounting Metrics for Airlines relative to the easyJet plc Annual Report and Accounts for FY2023 compared to FY2022. (Source: easyJet plc's Annual Report and Accounts, FY2023 and FY2022) . . . 85
5 SASB Activity Metrics for Airlines relative to the easyJet plc Annual Report and Accounts for FY2023 compared to FY2022. (Source: easyJet plc's Annual Report and Accounts, FY2023 and FY2022) . . . 86
6 SASB Sustainability Disclosure Topics & Accounting Metrics for Airlines relative to the Ryanair Group Sustainability Report's for FY2023 compared to FY2022. (Source: easyJet plc's Annual Report and Accounts, FY2023 and FY2022) . . . 92
7 SASB Activity Metrics for Airlines relative to the Ryanair Group's Sustainability Report for FY2023 compared to FY2022. (Source: Ryanair Group's Sustainability Report, FY2023 and FY2022) . . . 94
8 SASB Sustainability Disclosure Topics & Accounting Metrics for Airlines relative to the Lufthansa Group's Annual Report for FY2023 compared to FY2022. (Source: Lufthansa Group's Annual Report, FY2023 and FY2022) . . . 99
9 SASB Activity Metrics for Airlines relative to the Lufthansa Group's Annual Report for FY2023 compared to FY2022. (Source: Lufthansa Group's Annual Report, FY2023 and FY2022) . . . 101
10 Proportions of turnover associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by Deutsche Lufthansa AG in FY2023. (Source: Lufthansa Group's Annual Report 2023) . . . 103
11 Proportions of CapEx associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by Deutsche Lufthansa AG in FY2023. (Source: Lufthansa Group's Annual Report 2023) . . . 104

12 Proportions of OpEx associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by Deutsche Lufthansa AG in FY2023. (Source: Lufthansa Group's Annual Report 2023) 104
13 Proportions of turnover associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by KLM Royal Dutch Airlines in FY2023. (Source: KLM Royal Dutch Airlines Annual Report 2023) 113
14 Proportions of CapEx associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by KLM Royal Dutch Airlines in FY2023, where "[E]" denotes enabling activities and "[T]" transitional activities. (Source: KLM Royal Dutch Airlines Annual Report 2023) 114
15 Proportions of OpEx associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by KLM Royal Dutch Airlines in FY2023, where "[E]" denotes enabling activities and "[T]" transitional activities. (Source: KLM Royal Dutch Airlines Annual Report 2023) 115
16 Climate targets set by each airline under analysis. All the targets involving CO_2 emission reductions utilize 2019 as the baseline year. 117
17 Means and standard deviations for the data gathered from each question in the survey. 121
18 Frequencies of the demographic characteristics of respondents from *Question 1* to *Question 4* of the survey. 122
19 Part.1: Frequencies of the survey-specific questions' results (from *Question 5* to *Question 9 B.*). 127
20 Part. 2: Frequencies of the survey-specific questions' results (from *Question 9 C.* to *Question 12*). 128
21 Contingency table of the variables "climate awareness" and "gender". 138
22 Contingency table of the variables "climate awareness" and "age". 140
23 Contingency table of the variables "climate awareness" and "education". . . 142
24 Contingency table of the variables "climate awareness" and "air travel environmental impact awareness". 144
25 Contingency table of the variables "air travel environmental impact awareness" and "air travel frequency". 146
26 Contingency table of the variables "income" and "willingness to pay (low price difference)". 148
27 Contingency table of the variables "income" and "willingness to pay (high price difference, different airlines)". 150

28 Contingency table of the variables ”gender” and ”willingness to pay (low price difference)”. 152
29 Contingency table of the variables ”gender” and ”willingness to pay (high price difference, different airlines)”. 153
30 Contingency table of the variables ”age” and ”willingness to pay (low price difference)”. 155
31 Contingency table of the variables ”age” and ”willingness to pay (high price difference, different airlines)”. 157
32 Contingency table of the variables ”education” and ”willingness to pay (low price difference)”. 159
33 Contingency table of the variables ”education” and ”willingness to pay (high price difference, different airlines)”. 161
34 Contingency table of the variables ”air travel frequency” and ”willingness to pay (low price difference)”. 163
35 Contingency table of the variables ”air travel frequency” and ”willingness to pay (high price difference, different airlines)”. 165
36 Contingency table of the variables ”climate awareness” and ”willingness to pay (low price difference)”. 167
37 Contingency table of the variables ”climate awareness” and ”willingness to pay (high price difference, different airlines)”. 169
38 Contingency table of the variables ”air travel environmental impact awareness” and ”relevance of air travel impact on climate change”. 171
39 Contingency table of the variables ”air travel environmental impact awareness” and ”relevance of air travel impact on air quality”. 173
40 Contingency table of the variables ”air travel environmental impact awareness” and ”relevance of air travel impact on noise pollution”. 175

Abstract

Climate change stands as one of the most urgent issues of our time, prompting the present generation to adopt environmentally and socially friendly practices to drive sustainable development. Companies, as significant drivers of productivity and economic growth, must take prompt action to achieve decarbonization and meet the goals of the Paris Agreement. Accordingly, the air transport sector, a key enabler of economic and social development, plays a crucial role in this transition due to the significant impact of air travel emissions on climate change. In line with the prevailing sustainability movement, airlines are currently embracing various green solutions to meet stakeholders' growing demand for sustainability, demonstrating their accountability through sustainability reporting. Additionally, starting from the reporting year 2024, airlines will be required to align their core business activities thanks to the latter amendment of the EU Taxonomy, which extends the taxonomy's applicability to aircraft operators.

Studies indicate that airlines' eco-friendliness influences customer satisfaction, linking positive sustainability practices with customer loyalty and highlighting the critical role of a green reputation in airlines' growth and profitability. However, the study conducted as part of this work has revealed that customers are still developing trust in airlines' corporate sustainability efforts, believing that they may engage in sustainability practices only for profit purposes and thus generating greenwashing. Additionally, more than half of the sample subject to this research demonstrated to overestimate the environmental impact of aviation in terms of carbon emissions, believing it to be accountable for shares ranging from around 7% to around 21% of energy-related CO_2 emissions, when in reality, it accounts for "only" around 2%. These findings underscore the need to address misconceptions about climate change as a whole and the environmental impact of aviation.

Introduction

Climate change, one of the most critical and urgent issues nowadays, is shifting the present generation's attention to embracing friendly practices toward the environment and society to safeguard their own needs and future generations' ones, giving the origin to the sustainability development approach. According to IPCC's latest Assessment Reports, human activities are chiefly accountable for growing global warming and greenhouse gas (GHG) emissions levels, among which companies, principal drivers of productivity and economic growth, should take prompt action to reach decarbonization and the Paris Agreement's goal in time. In particular, the air transport sector, a principal enabler of economic and social development capable of connecting individuals and economies worldwide, plays a crucial role in such a transition path due to the complex contribution of air travel emissions to climate change. In particular, the air transport sector represents one of the main contributors to human-generated climate change, contributing to around 2% of global CO_2 emissions (IEA, 2023b), amounting to 3.5% when considering also non-CO_2 emiossions (H. Ritchie, 2024). Despite the several emission reduction measures already implemented, IATA expected the air traffic demand to almost double between 2016 and 2036 (IATA, 2017). The enormous pace at which air traffic is expected to grow reverts the compensation effects of the mitigation measures adopted, requiring immediate action from all air transport industry stakeholders to combine different emission reduction measures to effectively reach the long-term aspirational goal (LTAG) of net-zero CO_2 emissions by 2050 established by ICAO in 2022. Considering the current climate emergency and the growing importance of sustainability across economic sectors, airline companies are now adopting different green solutions to fulfill stakeholders' increasing demand for sustainability, discharging their accountability via sustainability reporting. Following a thorough theoretical analysis comprehending the presentation of the burgeoning role of sustainability within economic sectors, alongside an examination of the environmental and climate-related impacts of air traffic, as well as the key actions aimed at promoting sustainability initiatives undertaken by legislators and industry's stakeholders, this study endeavors to investigate consumers' environmental beliefs and awareness, alongside their responses regarding air traffic-related climate concerns. This investigation is conducted by administering a tailored survey aimed at discerning how end-users perceive and address aviation-related climate issues and sustainability practices embraced by principal industry stakeholders (i.e., airlines), with particular attention to their sociodemographic attributes and sustainability preferences.

1 Sustainability Background

More than 50 years ago, the awareness of the limited biocapacity of our planet was already a concern among society. In particular, in 1972, the Club of Rome published "The Limits to Growth", a report highlighting the urgent need for society to raise their awareness towards the finite physical limits of the planet (Robinson, 1973), preceding the emergence of the adoption of a sustainable behavior among individuals, then solidified in the subsequent decades.

Materializing for the very first time almost four decades ago, in 1987, in the well-known Brutland Report (denominated as "Our Common Future"), the concept of sustainability has become an increasingly common trending concept today, motivating individuals, politicians, policymakers, governments, and businesses to care more about the preservation of future generations and their needs as much as they care for present ones, establishing the concept of "*Sustainable Development*". One of the principal triggering rationales for the spreading of such sustainability tendency undoubtedly derives from the fact that the earth's biocapacity is finite, and as our population grows together with consumerism and resource depletion, this poses our planet with irreversible dramatic changes, which present generations should consider how to address.

Unfortunately, the present generation lives in an unsustainable world, using more resources than the ones our planet offers. Regarding resource depletion, mentioning "Earth Overshoot Day"[1] is paramount, as it is taking place earlier every year. Notably, the Earth Overshoot Day computation consists of a ratio between the earth's biocapacity (i.e., the amount of finite natural resources that our planet generates yearly) and humanity's Ecological Footprint (humanity's demand for the planet's resources in one year), and multiplying the result by the number of days in a year (EOD, 2024).

$$\text{Earth Overshoot Day} = \frac{\text{Planet's biocapacity}}{\text{Humanity's Ecological Footprint}} \times 365 \tag{1}$$

As Figure 1 below shows, the Earth Overshoot Day started occurring in late December during the 70s and in early August from 2010. This downward trend emphasizes the urgent need to improve sustainability in the planet, cities, energy, food, and population to move the Earth Overshoot Day date and lessen resource depletion (EOD, 2024).

[1]Earth Overshoot Day marks the date when humanity's demand for ecological resources and services in a given year exceeds what Earth can regenerate in that year. (EOD, 2024)

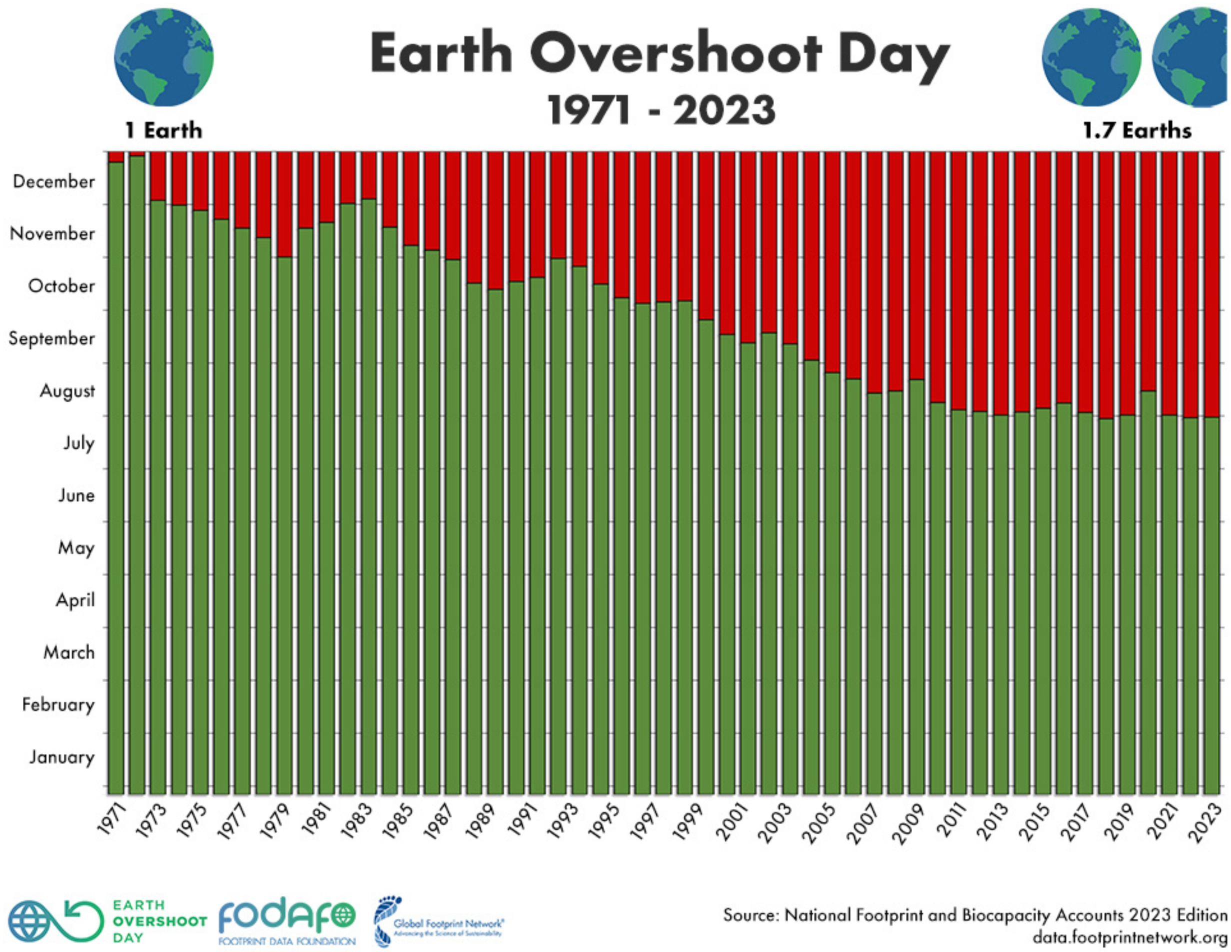

Figure 1: Earth Overshoot Day from 1971 to 2023. As the Figure displays, the Earth Overshoot Day occurrence demonstrated a downward trend in the last decades, occurring earlier each year. Source: https://overshoot.footprintnetwork.org/.

Additionally, the advancing economic development, increasing greenhouse gas (GHG) emissions, and companies' priority to achieve further development and profits pose a severe hazard to our climate: climate change. Due to the vast array of sectors affected by climate change impacts and economic growth threats (e.g., inequality), we can categorize sustainability into three dimensions: economic, environmental, and social.

Accordingly, sustainability leads to adopting a consequent "sustainable behavior" concerning the dimensions mentioned above, more devoted to preserving the present natural and physical resources for the future, delivering a more sumptuous extent of attention to environmental concerns, protecting human rights, and prioritizing long-term benefits rather than short-termism.

This section aims to explore and familiarize ourselves with the main peculiarities of sustainability, commencing from the presence of initial climate concerns to the first authentic appearance of sustainability as such in 1987, over the years and until current times; going further, we will define the concept of sustainable development, analyzing the main sustainability pillars and their applications, bringing attention on how principal actors in the economy, such as companies, embrace a sustainable approach in their practices.

1.1 Introducing Climate Change

Currently, climate change depicts one of the most critical concerns among present generations, boosting the urgent need to address all the climate-related risks and highlighting the necessity to care more about future generations' needs by preserving the planet's health and limited resources through mitigation and adaptation efforts, enabling sustainable development.
Climate change involves natural (e.g., from sun and volcanic activities) and anthropogenic (i.e., human-caused) long-term temperature shifts and changing weather conditions. Carbon dioxide (CO_2) and methane (CH_4) are The primary greenhouse gases responsible for climate change. In particular, carbon dioxide emissions stem mainly from burning fossil fuels (e.g., driving cars or heating buildings) and deforestation practices. On the other hand, agricultural sector activities and oil and gas operations are principally accountable for a significant part of methane emissions. Thus, the principal actors responsible for most greenhouse gas emissions are the energy, agricultural, transportation, and real estate sectors, as well as buildings and land use-related practices (UN, 2021).

According to scientific evidence scrutinized by the Intergovernmental Panel on Climate Change (IPCC), human activity was and is currently responsible for climate change to a more sumptuous extent, mainly because of the increasing amount of burned fossil fuels, producing hazardous emissions. In particular, according to IPCC AR 6 (2023) Working Group I[2], the current state of the climate highlights the evident influence of human activities on the level of warmth in all climate components (i.e., atmosphere, ocean, and land), displaying a probable range of global surface temperature increase from 0.8°C to 1.3°C in comparing the two time periods from 1850–1900 to 2010–2019 and an overall observed warming of 1.1°C (H. Lee et al., 2023a), as depicted by Figure 2 and 3.

[2]IPCC Working Group I scrutinizes physical scientific evidence related to climate change. Topics surrounded by such examination are changes in greenhouse gases and aerosols in the atmosphere, changes in air quality, global mean surface temperature, sea and ocean levels, rainfalls, droughts, and many others (Canadell et al., 2021).

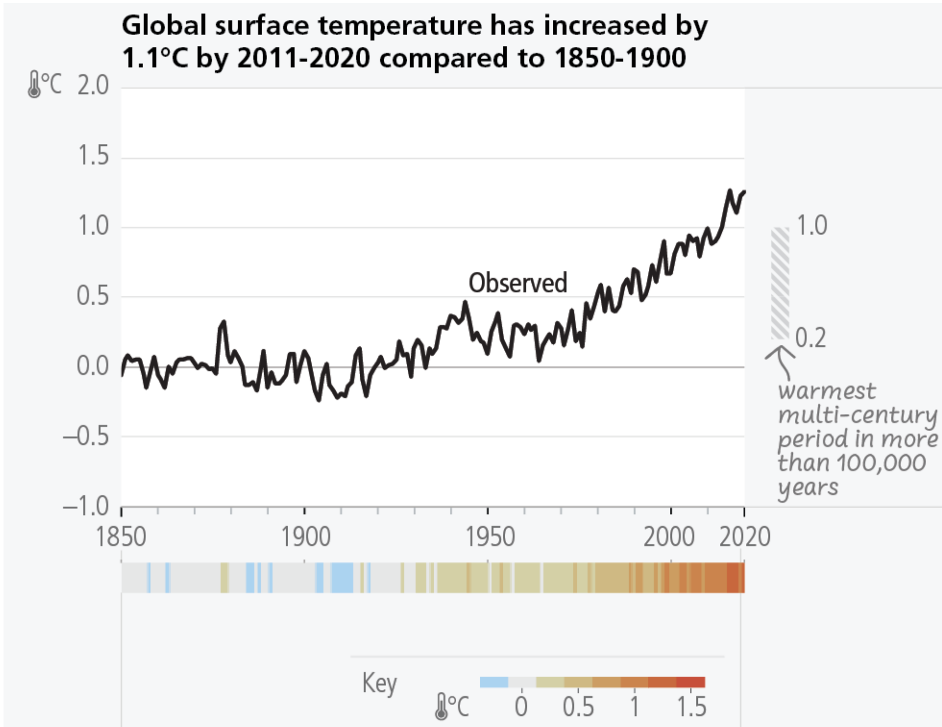

Figure 2: Change in the observed warming in global surface temperature between the two time periods, from 1850–1900 to 2010-2019. (Source: IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change)

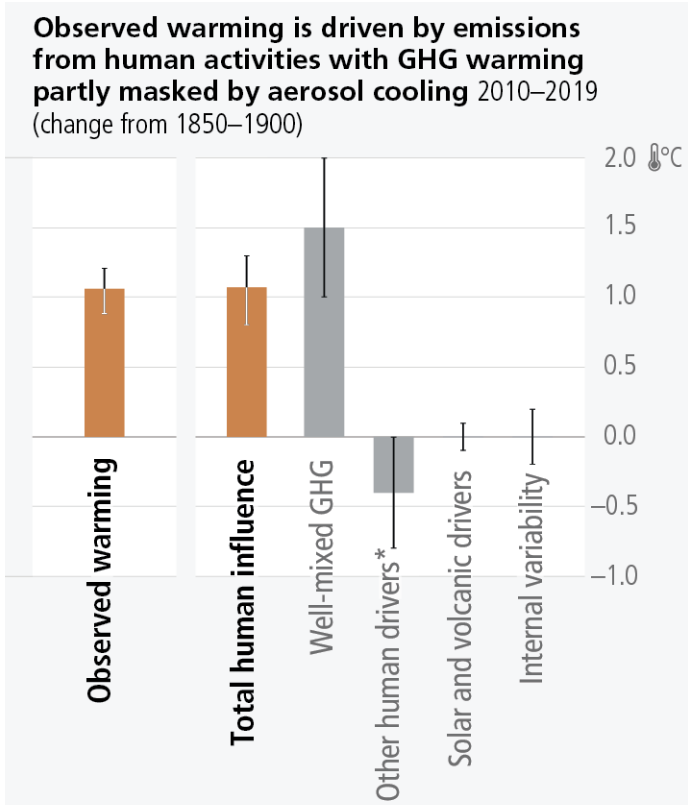

Figure 3: Change in the level of warming induced by mixed-greenhouse gas emissions, human activity, and natural sources of warming (e.g., solar and volcanic activities) in the period 2010-2019 from 1850–1900. The results exhibit severe increases in both atmospheric concentrations of several GHGs and total anthropogenic warming. (Source: IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change)

Notably, IPCC AR6 depicted a severe increase since 1970, faster than any other 50-year period in the last 2,000 years (H. Lee et al., 2023a). As Figure 3 displays, scientific recordings of the mixed concentration of greenhouse gases (GHG) demonstrate with high confidence that human activities mixed GHG emissions are undoubtedly responsible for most of the increases since around 1750. In particular, concentrations of methane (CH_4) and nitrous oxide (N_2O) demonstrated massive growth rates in the past 800,000 years. The same holds for current carbon dioxide (CO_2) concentrations, displaying their largest concentration over the past two million years (H. Lee et al., 2023a).

1.2 History of Sustainability

Despite the concept of sustainability seeming to be only a recent trending topic, the related environmental concerns, according to scarce recordings, date back to 500 BC, when environmental degradation deriving from human activities (e.g., farming, logging, and mining) started being discussed (Spindler, 2013).

Pre-Industrial Era During the Pre-Industrial Era, the environment started showing signs of environmental degradation and a significant increase in carbon dioxide (CO_2) emissions; these records demonstrates that human activity was already affecting the planet.

Industrial Revolution The Industrial Revolution marked a profound transformation of human society with momentous technological progress, leading to inequality in wealth distribution, increased raw materials exploitation, and the consequent greenhouse gases rise already noticed in the Pre-Industrial period. In 1798, Thomas Malthus notably foreshadowed that population growth would always exceed food supply.
During the 19th century, industrialization and its impacts on the environment and social relations started introducing growing discussions and awareness among the population. Consequently, the first environmentalist group was formed by the most concerned citizens, such as the Sierra Group, created in 1892; considering such a Group's publications, we would refer to them as sustainable development discussions today. One remarkable publication was by George Perkins Marsh in 1864, who predicted that human extinction on Earth would probably be provoked by human intervention and its related impacts on the natural environment (Dhanani, 2022).

1970s: Sustainability Outbreak After the growing environmental concerns conveyed by the overcoming of the Industrial Revolution in the past century, in the 20th century, especially after World War II, additional wealth and technological and societal refinements further proceeded their evolution together with urgent concerns about sustainability. In particular, a singular incident triggered the awareness of the seriousness of environmental concerns: the 1952 air pollution incident in London that killed dozens of thousands of people. After such an event, environmental concerns became worrisome to citizens, leading to the belief that further economic growth could have jeopardized the planet's and population's health. These worries were merely the starting signals of the climate tension affecting our society today. Afterward, these concerns grew globally during the 70s until the first Earth Day occurrence on April 22, 1970, and the Greenpeace foundation in 1971. During the same period, the United Nations held its first conference on the Human Environment, where victims of environmental-related disasters presented their concerns to governments to request action. Further, years after the UN conference, governments enacted the first pieces of legislation (Dhanani, 2022).

1987: Brundtland In 1987, sustainability finally evolved into a global concern after the publishment of the "Our Common Future" report by the UN Brundtland Commission, which provided the first popular definition of "*sustainable development*":

> *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*
>
> **Brundtland Commission**, 1987 report, Our Common Future

Even if this definition came as widely accepted by the community, nowadays, different definitions for "sustainable development" may provide different interpretations from the former. During the late 80s, a NASA scientist documented that the world climate was changing, increasing the awareness of climate concerns and driving businesses to consider environmentalism in their practices. As businesses approached environmentalism, the term "greenwashing" appeared for the first time due to the dubious "environmental" practices of a Hotel. As a result of such increasing awareness around climate concerns, consumers have started to modify their consumption habits, boosting the beginning of the production of new "sustainable" products.

1997: Kyoto Protocol Despite the local greenhouse gas (GHG) emissions sourcing, they still result in global diffusion, stressing the essential role of international cooperation to attain the desirable levels of emission reductions.
After the first COP in Germany in March 1995, on 11th December 1997, the United Nations Framework Convention on Climate Change adopted the first international treaty to address climate concerns through greenhouse-gases emission reductions on a global scale: the so-called Kyoto Protocol (UNFCCC, 2007).

> *"(...) the Kyoto Protocol operationalizes the United Nations Framework Convention on Climate Change by committing industrialized countries and economies in transition to limit and reduce greenhouse gases (GHG) emissions in accordance with agreed individual targets. The Convention itself only asks those countries to adopt policies and measures on mitigation and to report periodically."*
>
> **Kyoto Protocol** (UNFCCC, 2007)

The Treaty focuses only on developed and industrialized countries as the main actors liable for the more notable amount of GHG emissions in the atmosphere.

2015: Paris Agreement Almost two decades after the first international treaty, and after the adoption of the 2030 Agenda for Sustainable Development and SDGs (further described in *Section 1.3*) in September of the same year, on 12th December 2015 during the UN Climate Change Conference (COP21) in Paris, the UNFCCC recognized the urgent need to accelerate actions towards achieving a more sustainable future (UNFCCC, 2024). The 196 parties attending the Conference agreed to establish a legally binding international treaty on climate change, committing all Nations together to fight and adapt collectively against climate change and its related adverse effects: the so-called Paris Agreement.
The Paris Agreement's leading goal is to reinforce the global reaction to climate change-related threats by holding the global temperature increase below 2 degrees Celsius above pre-industrial levels and pursuing mitigation actions to limit the temperature increase even further to 1.5 degrees Celsius (UNFCCC, 2024). In addition to mitigation efforts, the agreement also focuses on increasing the resilience of countries facing climate change impacts through an improved mobilization of financial resources towards sustainable projects supporting low GHG emissions (UNFCCC, 2024).

2018: EU Action Plan on Sustainable Finance Following the international treaties in 1997 and 2015 and the integration of the 2030 Agenda for Sustainable Development and SDGs, Europe further proceeded its approach to sustainability with several strategies. Most notably, in March 2018, the European Commission published its Action Plan on financing sustainable growth, setting a comprehensive strategy outlining effective measures to incorporate sustainability at the financial level. The Commission Action Plan seeks to enable the creation of a financial system capable of stimulating the vision of sustainable development in the economy, society, and environment dimensions, contributing simultaneously to achieving the Paris Agreement and 2030 Agenda goals (EC, 2020d). This plan chiefly proposes a strategy outlining ten key actions broken down into three main categories:

(i) re-orienting capital flows towards more sustainable projects and investments, enabling a more sustainable economy (e.g., through the creation of EU Taxonomy and EU Green Bond Standard);

(ii) considering sustainability risks and opportunities in risk management processes and

(iii) fostering transparency and long-termism in investment decisions rather than short-termism (EC, 2020d).

In particular, the first key action of the category (i) consists of introducing a market transparency tool and accurate classification system for sustainable activities to label them as environmentally sustainable: the EU Taxonomy, an essential cornerstone of the European Union's sustainable finance strategy. The Taxonomy Regulation (2020/852/EU)[3] later implemented the EU Taxonomy classification system, published in June 2020 and entering into force in July 2020.

2019: European Green Deal (EGD) Presentation At the end of 2019, in Brussels, the European Commission presented the European Green Deal (EGD), a crucial and ambitious step in addressing sustainability concerns and directing society towards a more sustainable economy.

> *"The European Green Deal is our new growth strategy – for a growth that gives back more than it takes away. It shows how to transform our way of living and working, of producing and consuming so that we live healthier and make our businesses innovative. We can all be involved in the transition and we can all benefit from the opportunities. We will help our economy to be a global leader by moving first and moving fast. (...)"*

President **Ursula von der Leyen**, Brussels, 11 December 2019, European Green Deal Presentation (von der Leyen, 2019)

The plan chiefly addresses sustainability risks by turning them into opportunities across all economic sectors and policy areas, promoting a fair and equal transition. In particular, the European Green Deal presents a roadmap with actions ranging from optimizing resource use to safeguard the environment and stop climate change (i.e., promoting a circular economy) to specifying the investment and financing tools needed to guarantee a fair transition (EC, 2019).

In order to transform the EU into a modern and competitive economy while promoting efficient resource use, EGD sets three overarching objectives in its roadmap:

1. "becoming the first climate-neutral continent in the world by stopping greenhouse gas emissions within 2050;

2. promoting economic growth without relying on natural resources;

3. promoting an inclusive and fair transition for all, without leaving no person and no place out of its field of action" (EC, 2019).

[3]https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities

1.3 Sustainable Development

Considering the growing interest in sustainability across academic studies and literature, the sustainable development concept has broad meaning depending on the dimension assessed. However, despite the wide range of definitions developed for such a concept, sustainable development is primarily considered the United Nations' overarching long-term goal to benefit the environment and society. The first notable appearance of the phrase "sustainable development" dates back to 1980, when the International Union for Conservation of Nature (IUCN), in collaboration with the United Nations Environment Programme (UNEP) and the World Wildlife Fund (WWF), released the "World Conservation Strategy (WCS)" document, sub captioned "Living Resource Conservation for *Sustainable Development*" (WWF, 1980). The "Sustainable Development" concept took its basis with its official definition drawn up by the UN a few years after its first mention in 1980.

In 1987, the UN Commission in Brundtland depicted the sustainable development concept as a process of change emphasizing the importance of focusing on future generations' needs as much as present ones. The essential ingredient to fulfilling this development is a balanced set of actions between the economic and social needs of present generations envisioned to preserve the finite environmental capacity for future generations.

Sustainable development is thus a long-term process of change, redirecting investment decisions, capping exploitation of resources, and stimulating technological development (e.g., low-carbon technology) so that outcomes are compatible with future needs as much as present ones (Rogers, Jalal, & Boyd, 2012).

National Sustainable Development Strategy (NSDS) Additionally, the UN better reinforced this definition by developing the National Sustainable Development Strategy (NSDS), presented in Agenda 21 (Earth Summit, Rio de Janeiro, 1992). In particular, the NSDS was the first UN initiative to unite countries to the commitment "to integrate economic, social, and environmental objectives into one strategically focused blueprint for action", demanding an "institutional change" (UN, 2015).

Five years after the NSDS was elaborated, in 1997, Member States recalled and emphasized the importance of effectively implementing the strategy for all parties, setting a target for 2002 to track the contribution and progress of all adherent nations. In 2002, during the World Summit on Sustainable Development (WSSD), after receiving quite negative results from member states national reports tracking the progress of the NSDS, the adoption of the Johannesburg Plan of Implementation (JPOI) recalled again for commitment by member states, in particular:

"(...) *take immediate steps to make progress in the formulation and elaboration of national* *strategies for sustainable development and to begin their implementation by 2005. (...)"*

Paragraph 162 b, **Johannesburg Plan of Implementation (JPOI)**, 2002 World Summit on Sustainable Development (WSSD), retrieved from (UN, 2015)

Consequently, each country must design, at the best of its capacity, its long-term national sustainable development strategy according to its political, regulatory, historical, and environmental context.
After 2015, subsequently to the adoption of Agenda 2030 for Sustainable Development and its relative 17 Sustainable Development Goals (SDGs) that we will describe later, implementing national sustainable development strategies results deeply bundled with the integration of Sustainable Development Goals (SDGs) since they pursue the same core principles, tied to balanced and integrated economic, social and environmental objectives (UN, 2015).

UN Millennium Development Goals (MDGs) Later on, during the Millennium Summit (September 2000), the UN Member States adopted the Millennial Declaration, leading to the consequent development of the Millennium Development Goals (MDGs), a set of eight social goals ranging from diminishing extreme poverty rates to the increasing of the primary education provision by 2015 (UN, 2024). Subsequently, in January 2015, the negotiation process on the post-2015 development Agenda led to the elaboration of the 2030 Agenda for Sustainable Development, incorporating the upgraded version of the Millennium Development Goals (MDGs), the Sustainable Development Goals (SDGs) (UN, 2024).

UN Sustainable Development Goals (SDGs) The Sustainable Development Goals (SDGs) consist of 17 goals with a wide area of action, covering social, environmental, and economic issues. The SDGs recall the understanding of the sustainable development concept, underlining its fundamental role in integrating economic growth while preserving social well-being and environmental protection for future generations (UN, 2024).

Figure 4: The 17 Sustainable Development Goals (Source: UN Sustainable Development Goals website).

The progress on the SDG targets and the 2030 Agenda for Sustainable Development is monitored through yearly progress reports submitted by the UN Secretary-General, denominated "SDG Progress Report" (UN, 2024). These reports track the implementation progress of all SDGs through a solid framework of SDG indicators, statistical data gathered by national statistical systems, and information collected at the regional level (UN, 2024). The reports provide an overall examination of the implementation of the 2030 Agenda, emphasizing the consequences of the several crises on society and individuals' well-being, highlighting the areas where progress is lacking, and recalling urgent action to stimulate the progress required. An additional Global Sustainable Development Report is produced every four years, a quadrennial examination of the progress made in implementing the SDGs (UN, 2024).

1.4 Three Pillars of Sustainability

Analogous to the sustainable development vision promoted by the United Nations and solidified by the UN Sustainable Development Goals (SDGs) elaboration, the concept of splitting sustainability into three main sustainability pillars, social, economic, and environmental, has made its way. Specifically, this conceptualization emerged from the balanced set of actions required to reach sustainable development goals across economic, environmental, and social contexts, from which the three distinguished pillars have been devised. As of 2001, from the early stages, the literature recognized this concept as highly correlated with the vision of sustainable development, recalling its fundamental aspects (B. Giddings, Hopwood, & O'brien, 2002).

Again, according to a literature review, it can be deduced that the three pillars (social, economic, and environmental) framework principally roots from the opening era of sustainability development among society, namely from the Brundtland report in 1987, Agenda 21 in 1992, until the 2002 Earth Summit (Moldan, Janoušková, & Hák, 2012), evolving into the current widely known concept.

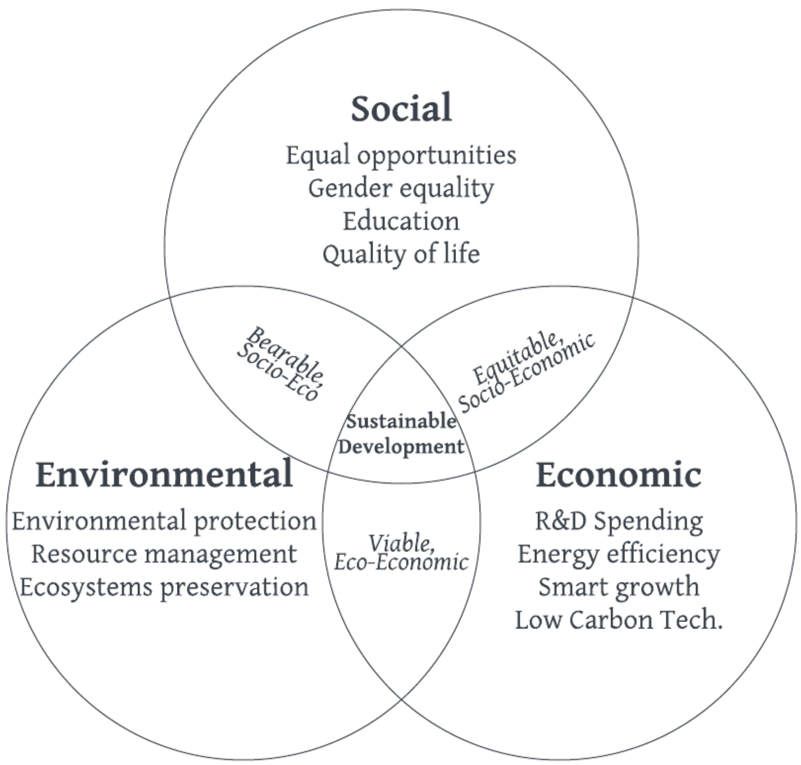

Figure 5: The sustainability pillars: social, environmental and economic.

Conforming to these considerations, these three pillars are intended to be the analogous components of sustainable development, regarded as the pillars of sustainable development, striving to enabling sustainable growth in social, economic and environmental areas.

Since the sustainability outbreak first occurs, governments, policymakers, organizations and people commit themselves to apply these three pillars in their practices to various extent. However, to achieve a full degree of sustainable development (see Figure 5), actors shall apply all three pillars evenly.

1.4.1 Economic Sustainability

Economic sustainability refers to all practices devoted to the conservation of natural and financial resources, ensuring financial stability in the long term. Analogously to the sustainable development definition, this consists of optimizing current resource consumption through innovation to ensure their availability for future generations, enabling future financial stability and growth.

1.4.2 Social Sustainability

Social sustainability consists of all actions committed to creating equal access, without prejudice, to primary necessities, such as food, water, clean air, and the environment for all individuals. Social sustainability also applies to the working environment, which is devoted to creating more fair and equitable employment systems, striving to stop worker exploitation and gender gaps.

1.4.3 Environmental Sustainability

Environmental sustainability focuses on efforts dedicated to safeguarding the environment by mitigating environmental damage and limiting natural resource consumption. The comprehensive objective of environmental sustainability is to limit resource depletion over time by slowing down the Earth's Overshoot Day occurrence to preserve current resource availability for future generations. This goal can be achieved by reducing fossil fuel consumption, diminishing logging and deforestation, preserving water, marine resources, and ecosystems, maintaining good air quality by diminishing pollution, and increasing recycling practices.

Each of these sustainability pillars is connected to the others. When the successful accomplishment of one dimension contributes directly to the realization of the others, it enables sustainable development. For instance, considering a company committed to achieving social sustainability, the former, implementing sustainability practices and measures in its business, will also achieve environmental and economic sustainability.

1.5 Businesses & Sustainability: The Concept of Corporate Sustainability

As sustainability topics evolved and gained relevance and the need for action to address sustainability-related risks became increasingly urgent, the significance of businesses' roles in addressing these issues raised, outlining the concept of "corporate sustainability". Nowadays, due to economic growth, corporations, especially larger ones, are increasingly impacting the three sustainability pillars, as well as they develop a sort of dependence on them. This phenomenon, combined with the sustainability trend, drives stakeholders to demand more sustainability from businesses. Corporate responsibility is, consequently, a way of conducting business to create sustainable value for stakeholders, promoting social, environmental, and governance strategies. A sustainable business is a corporation that positively impacts the economy, society, and environment pillars, striving to achieve the 2030 Agenda and its relative SDGs and promoting an effective transition towards a more sustainable economy.
Accordingly, becoming a sustainable business involves both inward and outward positive effects, with an economic focus on one side and a broader societal focus on the other. Hence, sustainability can benefit both the internal company and the outside environment, especially in the long term.

Sustainability Reporting As stakeholders' demand for sustainability information grew, corporations began to seek to communicate their sustainability efforts to external actors, earning legitimacy, enhancing their reputations, and further enabling the transition towards a sustainable society. Through the sustainability reporting mechanism, businesses can disclose their accountability, providing stakeholders with the required information about the actions taken to satisfy the sustainability performance expected.
The implementation of Directive 2014/95/EU on the disclosure of non-financial and diversity information (Non-Financial Reporting Directive, NFRD) further solidified the need for disclosing large businesses sustainable strategies and practices to the public, working as an effective means to increase transparency and accountability of organizations in social and environmental matters.

Non-Financial Reporting Directive (Directive 2014/95/EU, NFRD) The Non-financial Reporting Directive (Directive 2014/95/EU, NFRD), amending the Accounting Directive (Directive 2013/34/EU), was adopted in 2014 to further enable the transition towards a sustainable economy by combining corporations' ability to generate long-term profitability while safeguarding both the society and environment. In particular, Directive 2014/95/EU requires specific large undertakings falling under its scope to disclose non-financial information involving environmental and social matters, presenting the concept of double materiality, which distinguishes the undertaking's outward (i.e., impact materiality, the undertaking affecting the external environment) and inward (i.e., financial materiality, sustainability risks and opportunities affecting the undertaking performance and financial position) impacts, as represented in Figure 6.

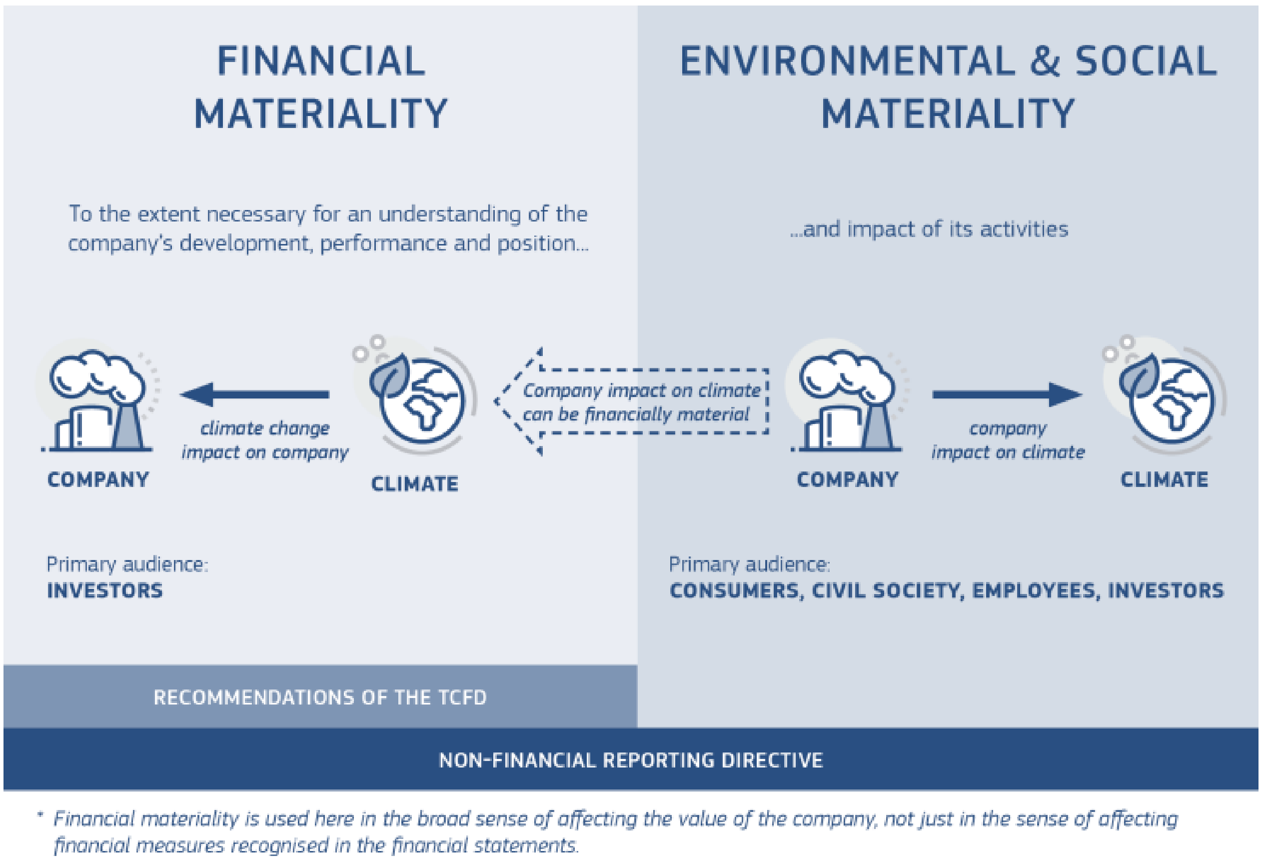

Figure 6: Non-Financial Reporting Directive double materiality perspective when reporting climate-related information. (Source: Guidelines on non-financial reporting: Supplement on reporting climate-related information (2019/C 209/01), European Commission)

As mentioned above, NFRD aims to enhance transparency, especially in large corporations in all economic sectors, by harmonizing social and environment-related information disclosure across the European Union, improving comparability. However, although the Directive endeavors to harmonize the disclosure of non-financial information, it still permits companies to implement its provisions in national jurisdictions flexibly. Concomitant therewith, companies can apply the sustainability reporting standard or framework they prefer when preparing their non-financial report.

Sustainability Reporting Standards The urgent need to attain a desirable level of harmonization in sustainability reporting led to a growing interest in standardizing sustainability (non-financial) reporting practices to foster comparability, quality, and consistency across reports. The widespread development of sustainability reporting standards, thus, focuses on improving the comparability and quality of corporations' sustainability reports (or non-financial reports).

Several types of sustainability reporting standards exist, developed by different global organizations and institutions at the international, European, and national levels. The most notable sustainability reporting standards are the following:

- Global Reporting Initative (GRI), an international set of frameworks and standards.
- International Financial Reporting Standards (IFRS) Foundation Standards and Frameworks developed and approved by the International Sustainability Standards Board (ISSB):
  - Sustainability Accounting Standards Board (SASB) Standards
  - IFRS S1 General Requirements for Disclosure of Sustainability-related Financial Information
  - IFRS S2 Climate-related Disclosures
  - Carbon Disclosure Standards Board (CDSB) guidance and framework
  - International Integrated Reporting Council (IIRC)
  - Taskforce on Climate-related Financial Disclosure (TCFD) recommendations

Corporations can decide whether to adopt one or more of these reporting standards when designing their sustainability reports, shaping their content accordingly.

Corporate Sustainability Reporting Directive (Directive (EU) 2022/2464 The Corporate Sustainability Reporting Directive (CSRD), proposed in 2021 and approved in 2022, was designed to enhance the above-described Directive 2014/95/EU (NFRD), filling the gaps of the latter and strengthening even more legislation on reporting social and environmental information that undertakings shall disclose. To improve the Non-Financial Reporting Directive effectively, the Commission led a public consultation to draft new ideas, identifying the areas of interest where the NFRD most needed enhancements. From the public consultation, it emerged the need to enlarge the scope of the application as well as include listed SMEs through a simplified set of standards, create mandatory sustainability reporting standards to enhance comparability across reports in the EU, establish the compulsoriness

of assurance (voluntary in the NFRD) and make mandatory the disclosure of materiality assessment processes.
Discussing sustainability reporting standards and the urgent need to harmonize and increase comparability in such context, the Corporate Sustainability Reporting Directive (CSRD) introduced and incorporated into its structure the European Sustainability Reporting Standards (ESRS), a set of standards mandatory for all undertakings falling under the scope of CSRD. The Directive 2022/2464, approved in 2022, entered into force on 5 January 2023.

2 Aviation Industry: Airlines and Sustainability

The aviation sector is a sector with the highest rate of growth worldwide, connecting people from country to country on an international scale, enabling global economic growth, and supporting around 11.3 million job positions worldwide (ATAG, 2023c), determining its fundamental role in modern society and its future to inevitably expand in the forthcoming years. Part of such a vast sector, the airline industry provides air transportation services to individuals and tourists by scheduling flights from and to numerous destinations worldwide. Nevertheless, air transport entails some costs at the expense of our planet and climate. In particular, air traffic contributes to the release of an extensive and increasing amount of GHG emissions, ranging from the usual CO_2 to other greenhouse gases (e.g., H_2O, NO_X, SO_2) and to the peculiar phenomenon of contrails, contributing substantially to global warming. Furthermore, aviation industry is accountable for other relevant environmental concerns, such as scarce air quality and noise pollution due to aircraft engine emitted noise and GHG emissions. In particular, air transport contributes around 2% of global energy-related CO_2 emissions (IEA, 2023b), amounting to 3.5% when considering also non-CO_2 emissions (H. Ritchie, 2024), displaying a more marked increase than other transport sectors due to the air transport demand quick recovery after the pandemic (International Energy Agency (2022), World Energy Outlook 2022, IEA). According to the International Transport Forum (ITF) scenarios, in the absence of technological developments and policies, aviation CO_2 emissions are expected to multiply by 2.5 between 2015 and 2050 (ITF, 2021).

Most notably, in 1999, the aviation industry's impact on climate became an urgent concern after the release of the Intergovernmental Panel on Climate Change report on "Aviation and the Global Atmosphere", following the International Civil Organization Authority (ICAO) interventions on reducing emissions of the whole aviation industry (Fichert, Forsyth, & Niemeier, 2020b).

Like many other businesses, the airline industry acknowledges the urgent climate emergency and the growing demand for sustainability from stakeholders and has undertaken steps to address these issues. In particular, they embrace sustainable practices and adhere to the Non-Financial Reporting Directive (NFRD) and the incoming Corporate Sustainability Reporting Directive (CSRD). Further, they are also incorporating industry-specific sustainability standards from the Sustainability Accounting Sustainability Board (SASB), specifically tailored for the airline industry, into their reports to ensure reliable reporting. This commitment to sustainability is a testament to the industry's recognition of stakeholders' role in shaping its future. Moreover, considering the air travel rebirth after the COVID-19 panic and the critical impact of emissions released by flights, organizations and policymakers commenced to consider adopting more efficient solutions to mitigate climate change to change GHG trajectories, both from a technical (e.g., aircraft structure and flight routes) and regulatory (e.g., carbon offsetting programs) point of view. This section explores the broad aviation sector, contrasting it with the airline industry dimension, analyzing its aspects and characteristics, and then considering its impacts on climate change and the relative environmental concerns. Afterwards, the section reviews how airlines approach sustainability via different practices plus some industry-specific standards that such organizations adopt to perform their non-financial reporting, finalizing with a closer look at the most reasonable solutions to reach sustainability goals proposed by organizarions, companies, industries, and policymakers.

2.1 Introduction to Aviation Industry

Across the transportation sector, air transport plays a pivotal role in realizing substantial economic growth and development, mainly thanks to its efforts to integrate global economies and its functionality in enabling connections across different countries. In particular, air transport refers to the aviation sector, which encompasses all the elements of air travel and the relative activities aimed at its facilitation. The aviation sector is one of the fastest-growing industries worldwide, enabling \$3.5 trillion (4.1% share)(ATAG, 2023c) in global GDP and defining its consequent substantial impact on emissions, contributing about 2% of energy-related CO_2 emissions globally (IEA, 2023b).
This sector comprises numerous actors, such as the broad airline industry, aviation maintenance, air traffic control and airports, aircraft manufacturing companies, research companies, military aviation, and many others. Despite the vast array of actors employed in this sector, the International Civil Aviation Organization (ICAO) breaks down the aviation sector into three distinguishable sectors:

1. Commercial Air Transport (CAT),
2. General Aviation (GA) and
3. Aerial Work (AW)

commercial, general, and military.

Commercial Air Transport (CAT) The commercial air transport or commercial aviation sector comprises all the activities related to the transportation of passengers or loads of cargo. The main characteristic drawing together those activities is their capital requirement

to fund a flight for passengers and goods. Generally, commercial aviation is the transportation that enables people to travel worldwide from state to state quickly, entailing the crucial role of commercial aviation in present and future society, determining its evident ongoing development across future years.
The predominant commercial aviation sector actors are airlines, which are organizations providing public air transport services (cargo and passengers) for different routes, distinguished into different categories according to their final consumer targets and business model:

- legacy (or "network") airlines,
- low cost carriers (LCCs) and
- ultra low cost carriers (ULCCs).

Therefore, we consider airlines as a fundamental part of commercial aviation, plus cargo freight transportation by air.

General Aviation (GA) and Aerial Work (AW) According to the International Civil Aviation Organization (ICAO), general aviation comprehends all civil aviation aircraft operations different from airline operations, including civilian non-commercial flights; general aviation operations include instructional flights, corporate and business flights, private flights, and personal travel (ICAO, 2010). On the other hand, aerial work aviation refers to flight operations carried out for particular services, such as agriculture, research and rescue, emergency flights, advertising by air, military, observation, and so on. However, despite the ICAO classification, the International Council of Aircraft Owner and Pilot Associations (IAOPA) merged General Aviation and Aerial Work into one category (GA/AW) for convenience (ICAO, 2009), including all the abovementioned categories (IAOPA, 2024).

2.1.1 Aviation Industry vs. Airlines

As mentioned in the section above, three distinct categories of air transport belong to the aviation sector macro-category: commercial, general, and aerial work. In particular, considering the airlines' context, we are dealing with commercial aviation. Accordingly, we must differentiate and contrast these two terms to avoid the incorrect interchangeable use of these words, stressing that the airline industry is only a portion of the vast dimension of the aviation sector.

2.2 Air traffic and Environmental Concerns

In recent years, after the crisis in airlines induced by the COVID-19 pandemic, air traffic has been experiencing a recovery period, increasing and expected to reach, according to scenarios developed by the International Transport Forum's (ITF) 2021 Transport Outlook (ITF, 2021), the pre-pandemic levels. Although this rush has a positive effect from an economic growth perspective, the increase in air traffic entails some non-negligible environmental concerns. Actually, ITF's scenarios demonstrated that, in the absence of technological developments and policy measures, aviation CO_2 emissions would be multiplied by 2.5 between 2015 and 2050 (Clarke, Flachenecker, Guidetti, & Pionnier, 2022). Additionally, climate risk deriving from inaction regarding expanding aircraft emissions can translate into investment risk due to the strong correlation between increasing CO_2 emissions capable of hindering socio-economic development (Hildebrand & Donilon, 2020). Therefore, inaction concerning emission reductions can lead to climate-related financial risks and investment instability (Fink, 2020).

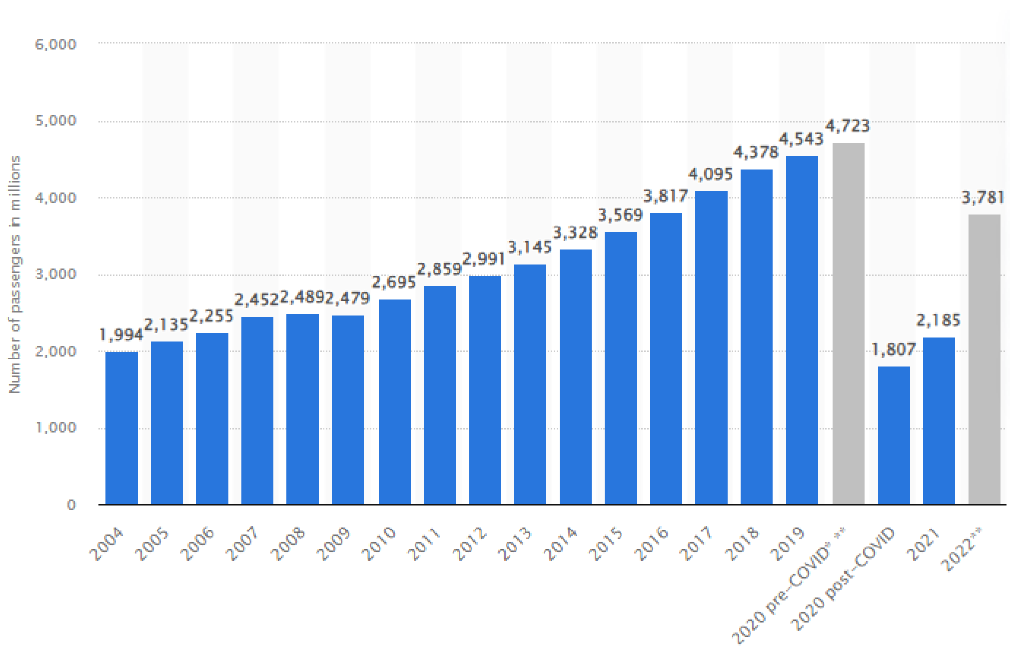

Figure 7: Number of scheduled passengers boarded by the global airline industry, in millions (2004-2022). (Source: statista.com)

By examining Figure 7, we can observe a steady increase in number of passengers in the 2010-2019 period, where the pre-pandemic peak hits. Further, after the crisis, we can notice a marked increase from the number of airline passengers during the post-COVID period to those forecasted for 2022, experiencing a 109.23% increase, approximately 80% of the pre-pandemic peak reached in 2019. According to forecasts, CO_2 emissions are expected to rise rapidly in response to the recovery in demand for air travel, exceeding the peak reached in 2019 around 2025 (IEA, 2023a).

In particular, aircraft engines contribute dramatically to the climate's state, altering the atmosphere composition through their CO_2 and non-CO_2 emissions from fossil fuel combustion. Furthermore, aircraft engine exhaust fumes contribute to air pollution due to the amount of pollutants released during jet fuel combustion. However, despite several policy measures (e.g., Air Quality Directive 2008/50/EC) and pollutant reduction efforts, pollution originating from air traffic drastically increased nevertheless. Other than air quality adverse effects, aircraft engines also produce noise pollution, disturbing the quiet of individuals living near airports and raising the probability of developing cardiovascular disease (CVD).

2.2.1 The Impact on Climate change

Aircraft emissions Emissions produced by aircraft engines, characterized by a variety of emissions both released during ground operations (10% of emissions) and cruise altitudes (90% of emissions) (CAA, 2017), peculiarly impact the climate by altering the amount of greenhouse gases composing the atmosphere, leading to the well-known greenhouse gas (GHG) effect, producing Long Wave (LWR) and Short Wave (SWR) Radiation, responsible for warming the earth surface and the lower layers of the atmosphere.

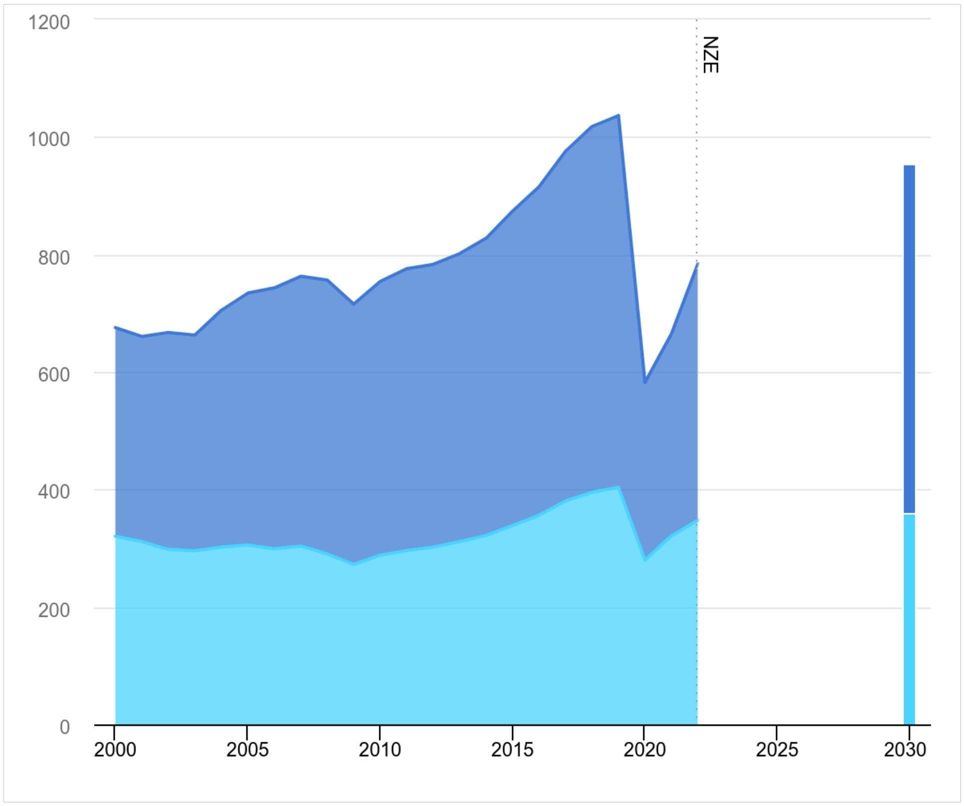

Figure 8: Direct CO_2 emissions from fossil jet kerosene combustion in aviation (international and domestic aviation) in the Net Zero Scenario, 2000-2030 (Source: International Energy Agency (2022), World Energy Outlook 2022, IEA, CO_2 emissions in aviation in the Net Zero Scenario, 2000-2030).

By observing Figure 8, we can notice how the post-pandemic recovery in the number of airline passengers (previously illustrated in Figure 7) had a significant impact on the amount of emissions released in international aviation, reaching almost 80% (436.72 Mt CO_2) of pre-pandemic levels (622.53 Mt CO_2) in 2022 (IEA, 2023b).

Main aviation pollutants Aircraft emissions influence and vary the atmosphere composition, contributing to global warming particularly complexly. The impact intensity differs according to distinct factors, such as the type of greenhouse gas (GHG) emitted, cruise altitude, and other parameters (e.g., meteorological conditions). Emissions and particulates that are released stem mainly from burning jet fuel (i.e., kerosene).
Thus, we can distinguish diverse greenhouse gases (GHG) impacting the climate.

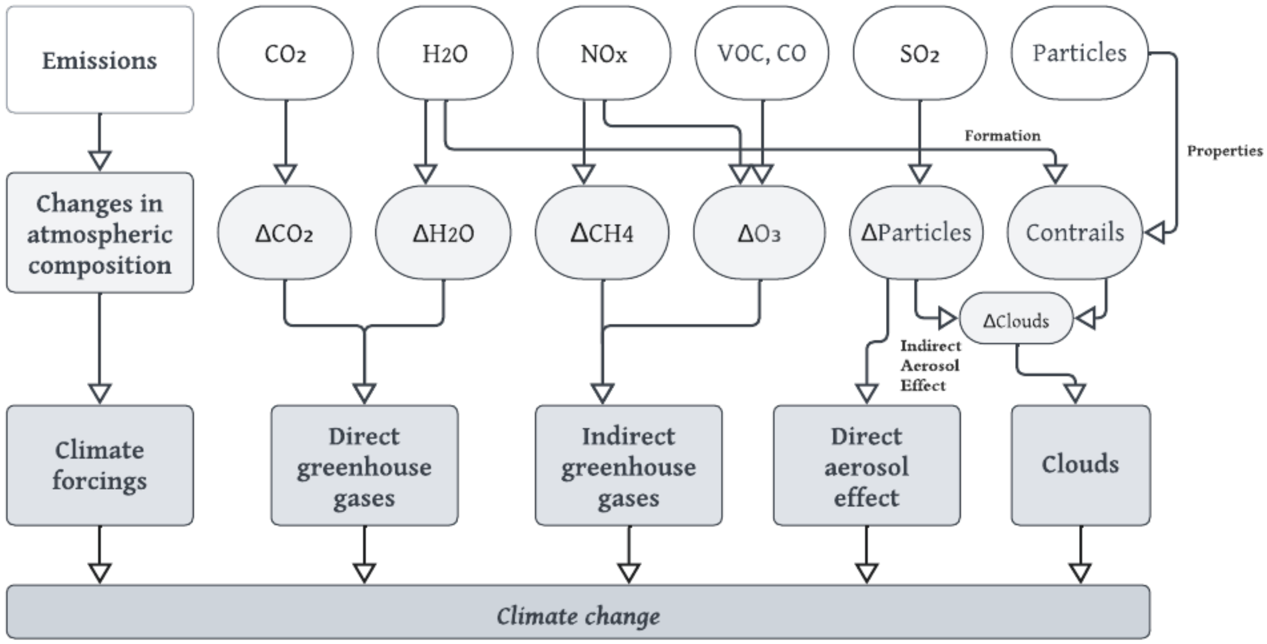

Figure 9: Schematic representation of air traffic climate impacts. Adapted by (Source: Fichert, F., Forsyth, P., & Niemeier, H. M. (2020). Aviation and Climate Change. Abingdon: Routledge).

Carbon Dioxide (CO_2) Carbon dioxide (CO_2) is the prevailing anthropogenic greenhouse gas (GHG) emitted by aircraft engines, constituting roughly 70% of exhaust fumes, stemming from fossil fuel combustion of kerosene (EESI, 2022). According to the Intergovernmental Panel on Climate Change (IPCC), commercial aviation contributes roughly 2% of anthropogenic carbon dioxide (CO_2) emissions (IEA, 2023a). In particular, kerosene burning produces CO_2 at the specific ratio of 3.15 kilograms of CO_2 per 1 kilogram of fuel combusted (Penner, Lister, Griggs, Dokken, & McFarland, 1999), irrespective of the flight's phase (i.e., altitude) (Wey & Lee, 2017); the volume released then varies according to other factors specific to the aircraft (e.g., aircraft efficiency and load carried) and the distance traveled.

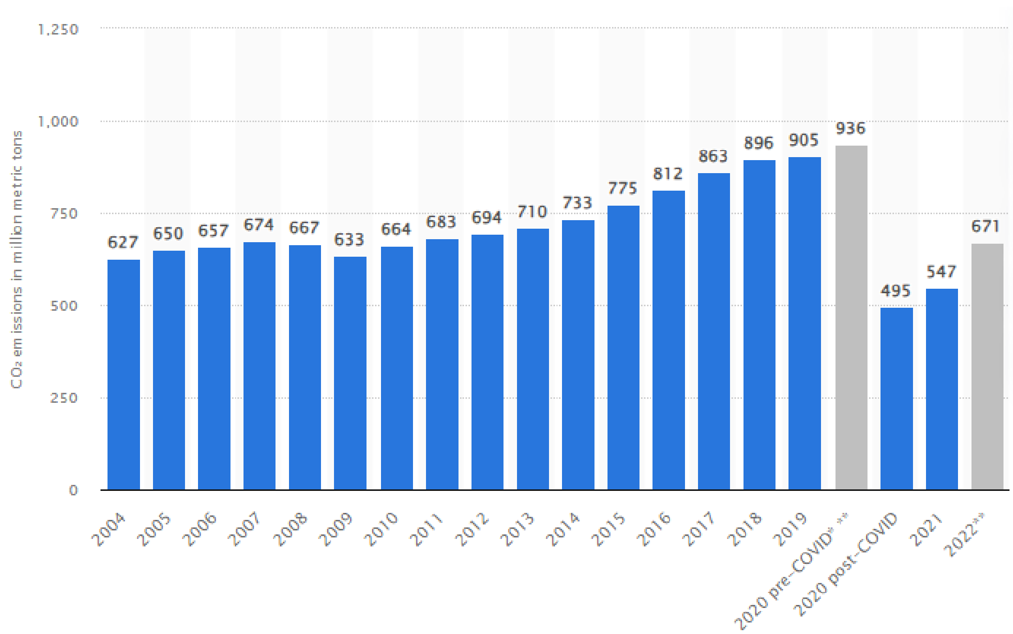

Figure 10: CO_2 emissions (in million metric tons) from worldwide commercial aviation 2004-2022. (Source: statista.com)

Figure 10 shows how air traffic CO_2 emissions dramatically increased during the last two decades, in reaction to the increasing demand for scheduled passengers displayed in Figure 7.
As a reaction to this dramatic rise, the amount of CO_2 in the atmosphere also increased due to accumulating emissions. The central cause for such a growth is the peculiar longevity of CO_2, marked by a long decay process, defining its non-negligible potency as a greenhouse gas. In particular (Grewe, 2020), carbon dioxide (CO_2) emissions can persist in the atmosphere for hundreds to thousands of years (Solomon et al., 2007), accumulating over the years and further increasing CO_2 concentrations.

Non-CO_2 Greenhouse Gases (GHG) Beyond carbon dioxide, further greenhouse gases (GHG) significantly impact the climate, changing the atmospheric composition, either directly or indirectly. Greenhouse gases can directly impact the climate if their emissions instantly modify the atmosphere's composition; conversely, they have an indirect impact if they alter the atmospheric composition through chemical or micro-physic reactions.
Contrary to CO_2, these gases have a lower longevity and faster decay process, influenced by different factors, such as the location (latitude, altitude, and longitude) and time, as well as the meteorological conditions during the release of emissions. As a result, the lifetime of non-CO_2 gases differs according to specific conditions, resulting in generally shorter than carbon dioxide (Grewe, 2020).

More precisely, when burning kerosene, aircraft engines produces some exhaust fumes, composed by CO_2, water vapour (H_2O), nitrogen oxides (NO_x), unburned hydrocarbons (HC), carbon monoxide (CO) and sulphur oxides (SO_2), soot, plus some traces of hydroxyl family and nitrogen compounds (Masiol & Harrison, 2014).

Water vapor (H_2O), an essential natural greenhouse gas, constitutes around 30% of exhaust fumes from jet fuel combustion (FAA, 2005). When emitted by aircraft engines, water vapor exhausts within a relatively short period, from days to weeks, having a brief life span in the troposphere. It can have a meaningful impact only if its emission occurs at altitudes superior to the tropopause, where the stratosphere is located. This area's peculiar conditions (i.e., stratification of the latter) favor the accumulation of water vapor, leading to a direct climate impact (see Figure 9).

Nitrogen oxides (NO_x) are those gases that interact through chemical agents in the atmosphere, producing some types of indirect greenhouse gases that can both warm or cool the atmosphere, yielding the so-called "net NO_x" effect (ICAO, 2022). For instance, in a very short period, NO_x's interaction can induce the generation of ozone (O_3), having a warming effect; further, its interaction can lead to the formation of methane (CH_4), having a cooling impact conversely, lasting for decades. Although aircraft engines emit nitrogen oxide (NO_x) in relatively small amounts, they can still influence the ozone (O_3) generation process.
Nevertheless, despite the positive amounts generated by the cooling effects of methane, the ozone resultant warming effect overcomes the former, leading to the current overall result of net warming (EASA, 2024).

Contrails Contrails are one of the outstanding air traffic impacts affecting the climate, together with their transition toward contrail-cirrus clouds, commonly referred to as contrails. These contrails form at the back of aircraft's engines, generally at altitudes between 26,000 and 39,000 feets, due to the mixture of hot and humid exhaust, producing water vapor (H_2O), with neighboring air, leading to air saturation with water (Grewe, 2020). This process leads to the formation of droplets, freezing when the air is sufficiently cold enough, together with particles present in exhaust fumes, forming ice crystal nuclei (ATAG, 2023a). As the atmosphere reaches sufficiently cold and humid conditions, the tiny ice crystals grow in size, gathering the water vapor already present in the atmosphere, forming contrail, inducing the formation of contrail-cirrus clouds. These contrail-cirrus clouds, snaring infrared rays, can yield a warming effect up to three times higher than the CO_2 impact (EESI, 2022).

Notwithstanding their temporary persistence in the atmosphere (up to a few hours), contrails still severely contribute to global warming (Fichert et al., 2020b). The main reason behind this statement is the increasing number of daily flights, which produces a powerful warming effect when combined with the contrails' warming effect. Nowadays, the effects of contrails exceed the total warming effect produced by the comprehensive CO_2 amount emitted since the beginning of engine-powered flights (Kärcher, 2016).
As mentioned before, H_2O itself has a brief lifetime in the atmosphere, ending with a limited small direct impact on the climate. However, its presence in exhaust fumes contributes to the formation of contrails, indirectly affecting warming to a greater extent.

2.2.2 Air quality

Other than climate change effects, aircraft engine emissions can influence the local air quality, increasing air pollution. The consideration of air pollution is crucial due to the potentially hazardous effects it can have on the health's population. In the last decade, the European Union has strived to reduce overall emissions of air pollutants and improve air quality through different policy tools, such as the EU Ambient Air Quality Directive (Directive 2008/50/EC). However, despite these decisive efforts, the concentration of air pollutants in the air stemming from air traffic still increased throughout the EU. In particular, Directive 2008/50/EC sets regulatory thresholds for some air pollutants' concentrations in ambient air, namely particulate matter (PM), Nitrogen dioxide (NO_2), ozone (O_3), and sulfur dioxide (SO_2) (EC, 2008).

Aircraft engines, analogous to other vehicle engines operating through fossil fuel combustion, produce equivalent emissions, most notably nitrogen oxides (NO_x), particulate matter (PM), volatile organic compounds (VOCs), sulfur dioxide (SO_2), carbon monoxide (CO) and unburnt hydrocarbons (HC) (EASA, 2022a). These emissions can stem from general aircraft operations at lower altitudes (e.g., take-off) and, in a minor part, from ground support operations (e.g., taxiing, landing gear & control surface movement, surface access road transport, and others), concentrating the prevalence of air pollution near airports, affecting nearby locations' local air quality. However, according to literature, high-altitude operations can also produce emissions capable of affecting atmospheric air quality at the same layer where people are exposed enough to suffer health consequences (Barrett, Britter, & Waitz, 2010).

Nitrogen oxides (NO_x) Aircraft engines produce nitrogen oxides (NO_x), especially during take-off, when the pressure and the temperature of the combustor reach high conditions (Schumann, 2002).
Direct exposure to nitrogen oxide emissions can be particularly hazardous to human health.

In particular, long-term NO_x exposure can lead to immune system impairment, respiratory problems, and damage to lung tissues. Additionally, NO_x can trigger some chemical reactions, leading to the formation of secondary particulate matter, resulting in an indirect contribution to air pollution (EASA, 2022a).
As mentioned in *Section 2.2.1*, NO_x, when reacting with other gases, can form ozone (O_3). In particular, this occurs when nitrogen oxide, in the presence of sunlight and warm conditions, interacts with volatile organic compounds (VOCs), hydrocarbons (HC), and carbon monoxide (CO), leading to ozone formation and the well-known smog at ground level, altering air quality hazardously and potentially undermining human health (Yim et al., 2015)(Jonsdottir et al., 2019).

Particulate matter (PM) Particulate matter refers to two categories of particulates:

- non-volatile (nvPM) or
- volatile particles (vPM).

Such particulates consist of solid particles and watery droplets contained in the air. Particulate matter appears in different sizes and compositions; according to its size, it can be large enough to be seen with the naked eye or very small, requiring the utilization of an electron microscope to be visible. Aircraft engine exhaust fumes mainly contain non-volatile particles (nvPM) composed of soot or carbon (EC, 2020b). As mentioned before, the European Union put some limits on the emissions of certain air pollutants with the Directive 2008/50/EC on air quality. In particular, it established thresholds in air quality for two distinct particulate matter concentrations: PM_{10} (inhalable particles, diamater of $\leq 10\mu$m) and $PM_{2.5}$ (fine inhalable particles, diamater of $\leq 2.5\mu$m).
$PM_{2.5}$ are the finest inhalable particles, classified as the best proxy for risk, posing human beings with serious health problems, such as cardiopulmonary diseases and lung cancer (Kapadia et al., 2016).

Sulfur dioxide (SO_2) Sulfur dioxide (SO_2) emissions are generated by aircraft engines when burning fuel containing sulfur. Fuel sulfur content (FSC) measures the sulfur in aircraft engine fuel, currently ranging between $\approx$ 600 and 800 ppmv (parts per million by volume), with a current limit of 3,000 ppmv (EC, 2020b).
Sulfur dioxide emissions produce additional particles, such as soot and sulfate particle emissions. These extra generated particles (ΔParticles) alter, in turn, particle concentrations and radiative transfer, producing the so-called direct aerosol effect (see Figure 9).
According to a literature review, air traffic "non-CO_2 emissions with a fuel sulfur content

(FSC) of 600 ppm result in ≈ 3600 [95 % CI: 1310–5890] annual premature mortalities globally due to increases in cases of cardiopulmonary disease and lung cancer", driven mainly by the increasing concentration of $PM_{2.5}$ at ground-level (Kapadia et al., 2016).

Ozone (O_3) Ozone (O_3) results as an indirect pollutant of air traffic, deriving from the chemical reaction of oxidization between nitrogen oxides (NO_X) and carbon monoxide (CO) or volatile organic compounds (VOCs) in the presence of sunlight and warm conditions (EASA, 2022a).

As mentioned before, NO_X, when reacting with other gases, leads to ground-level ozone formation, generating the smog phenomenon. When in consistent quantities, the smog can undermine people's health, provoking respiratory problems and damaging the environment, jeopardizing crop growth and ecosystems.

2.2.3 Noise pollution

Although noise production from single aircraft has diminished by 75% (EC, 2024a) over the last three decades thanks to technological enhancements, noise generated from the continuously growing air traffic remains a concern for citizens, especially for those living in the vicinity of airports. Aircraft noise pollution is one of the causes of most adverse opinions of communities concerning airport daily operations and their expansion (ICAO, Balanced Approach to Aircraft Noise Management). In light of the above, several residents living near airport areas complained about noise disturbance through petitions in the last decades, requiring action to adopt mitigation measures. Despite petitioners demonstrating only partial awareness of noise disturbance health impacts, they nonetheless show relative concern about the substantial increase in air traffic over a relatively small period, as shown by a study conducted by the Policy Department for Citizens' Rights and Constitutional Affairs at the request of the European Parliament's Committee on Petitions (PETI committee) concerning noise disturbance (Elliff, Cremaschi, & Huck, 2020).

Exposure to noise disturbance can have potential negative effects on health and well-being, especially for those residents living near airports. The most notable health effects that extra noise exposure can induce are stress-caused annoyance, sleeping disorders, learning difficulties in toddlers, and heart problems (e.g., cardiovascular disease (CVD) and ischaemic heart disease), which may provoke premature mortalities.

The World Health Organization (WHO) established thresholds in sound pressure levels for daytime and nighttime aircraft noise in its Environmental Noise Guidelines (EU), holding them at L_{den}[4] 45 dB and L_{night}[5] 40 dB to reduce the relative adverse health impacts and to ensure the sustainability of air traffic (EASA, 2022b).

To ensure the effectiveness of its noise-related measures, the European Union adopted, in 2014, Regulation (EU) 598/2014 on the procedures concerning the introduction of noise-related operating restrictions, repealing the Environmental Noise Directive (END, Directive 2002/49/EC) previously adopted in 2002. Furthermore, the mentioned regulation complies with the International Civil Aviation Organization's (ICAO) international principles on noise management, known as the "Balanced Approach"[6]. In particular, the "Balanced Approach" concept adopted by the International Civil Aviation Organization (ICAO) consists of a common approach aimed at identifying noise concerns within airports and presenting new efficient solutions to these problems. As mentioned earlier, noise disturbance concerns can lead to airport operational restrictions due to residents' opposition to constructing new airports and expanding existing ones. In light of these facts, the ICAO's concept is the best standard approach to address aircraft noise concerns in an environmentally and economically responsible manner. In particular, the "Balanced Approach" concept adopted by the International Civil Aviation Organization (ICAO) consists of an approach aimed at identifying noise concerns within airports and presenting various solutions. As mentioned earlier, noise disturbance concerns can lead to airport operational restrictions due to residents' opposition to constructing new airports and expanding existing ones. In light of these facts, the ICAO's concept is the best standard approach to address aircraft noise concerns in an environmentally and economically responsible manner. The ICAO's "Balanced Approach" is based on a list of principles designed to aid airports in enhancing the management of ground noise effects. The approach builds upon four main pillars (*International Civil Aviation Organization (ICAO), Balanced Approach to Aircraft Noise Management*, 2020):

1. **Reduction of noise at source:** consists of measures prescribing the adoption of noise certification standards based upon ICAO responsibility.

2. **Planning and management:** strategy delimitating areas around airports based on their noise level, for which local and municipal governments are responsible

3. **Noise abatement operational procedures:** resulting as the most effective measures, they consist of modifications on aircraft operations, such as utilization of specific runways rather than others, periods of delay, preferential routes and others.

[4]Day Evening Night Sound Pressure Level.
[5]Night-time sound pressure level.
[6]Balanced Approach (ICAO Doc 9829 AN/451).

4. **Operating restrictions:** measures which can prescribe the phasing out of specific aircraft. These restrictions can have side economic effects. Hence, they shall only be used when the abovementioned measures are ineffective.

Adopting such legislation provided airports with the implementation of noise mitigation measures through specific action plans. These action plans require applying measures related to air traffic management, operational restrictions, and some economic measures in large-scale airports, which are the principal source of aircraft engine noise pollution (*International Civil Aviation Organization (ICAO), Balanced Approach to Aircraft Noise Management*, 2020).

2.3 Literature Review

Air traffic climate impact Given the notable expansion potential of the aviation industry and air traffic, it is foreseeable that its relative greenhouse gas emissions will increase accordingly, thereby solidifying the aviation sector's status as one of the sources with the highest growth-rate of greenhouse gas (GHG) emissions (EC, 2020a), encompassing both CO_2 and non-CO_2 emissions, compared to all the others modes of transportation. Global aviation emissions have doubled over the past two decades, underscoring the sector's non-negligible environmental impact. Moreover, predictions suggest a substantial rise in CO_2 and NO_X emissions, the principal greenhouse gases contributing to air transport's climatic effects, with expected increases of approximately 21% and 16%, respectively, by 2040 (EEA, 2019). Nevertheless air traffic results accountable for global CO_2 emissions for around 2% (IEA, 2023b), its comprehensive contribution to global warming, due to the impacts related to its emissions of other nocive greenhouse gases (e.g., NO_X, SO_2 contrails, O_3 and others), results even higher. In particular, recent research estimated that aviation contribution to "radiative forcing" (i.e., contribution to global warming) in the period from 2000 to 2018 was around 3.5% (D. S. Lee et al., 2021). Furthermore, some studies estimated that the aviation industry has been responsible for around 4% of global warming compared to the pre-industrial period (Klöwer et al., 2021). Concerning CO_2 emissions, research indicates that there is high confidence around the CO_2 effects stemming from aviation and their relative radiative forcing (H. Lee et al., 2023a). Despite the existence of several scientific studies concerning the non-CO_2 impacts deriving from air traffic, such as the ones caused by NO_X (Skowron, Lee, & De León, 2015)(Pitari et al., 2015) and contrails (Ghosh et al., 2024)(Matthes et al., 2017), these topics are currently surrounded by a significant degree of uncertainty, alongside the potential mitigation measures to reduce their effects (D. S. Lee, 2018)(D. S. Lee et al., 2023). Accordingly, feasible and effective measures to address non-CO_2 effects in the aviation industry are absent (Hemmings et al., 2020).

Aviation & Sustainability Thus, considering the widespread embracement of sustainability among all economic sectors to pursue the Paris Agreement goal, the aviation industry shall play its role accordingly, adopting green solutions and practices to address sustainability and its industry climate-related concerns. However, according to literature findings, despite the intense efforts to reduce emissions in the airline industry, greenhouse gas emissions are undoubtedly going to rise significantly due to the extensive pace at which air traffic is expected to grow (Wang, Huang, & Chen, 2019). Accordingly, addressing issues concerning CO_2 and non-CO_2 emissions and related effects and creating a balanced approach between those issues remains paramount for aviation industry stakeholders when considering industry-specific sustainability concerns (Kucukvar et al., 2021). Currently, by embracing sustainability and adopting measures to reduce its emissions, such as the employment of sustainable aviation fuel, carbon offsetting measures, and new-generation aircraft, the aviation industry has already significantly made substantial progress in reducing its carbon footprint in its business compared to 1990 (ATAG, 2020).

Despite the current finite limits of technological innovation in aircraft advanced technology, according to literature findings, technical enhancements of the aircraft power systems (i.e., aircraft electrical systems that generate, regulate, and distribute electrical power throughout the aircraft) are a crucial step to delivering fuel-efficient aircraft and fewer emissions. Again, future advancements in aviation propulsion technology could be strongly driven and positively affected by innovation in hybrid propulsion technology (Felder, Brown, DaeKim, & Chu, 2011). Accordingly, further research claims that technological innovation and new hybrid-electric propulsion systems are expected to play a pivotal role in extensively reducing CO_2 and NO_X emissions in the airline industry, especially during the airline operational phase[7] of the life cycle (LC) period (Bai et al., 2020). In particular, the mentioned study analyzed the simulation of hybrid unmanned aerial vehicle (UAV) under conventional cruise flight and the terrain tracking phase. Notwithstanding that, the airline industry can also impact the environment in other stages of LC, ranging from feedstock extraction to manufacturing and aircraft dismantling activities. Thereby, sustainable practices in the airline sector shall comprehend all the LC phases where the former activities could significantly lead to ecological impacts.

Prior research suggests that the aviation industry, to pursue the sustainability path effectively, shall ratify appropriate measures and practices capable of upholding the environmental dimension while nourishing economic growth and stability, having regard for ensuring society's quality of life. Thereby, the aviation industry shall carefully consider its accountability

[7] Airline operation phase comprehend flight planning, scheduling, aircraft maintenance, passenger and cargo handling, ground operations, crew management, and in-flight services activities.

for its impact on the three sustainability pillars, ensuring compliance with the environmental, economic, and social dimensions (Alameeri, Ajmal, Hussain, & Helo, 2017).

Sustainability practices in aviation Considering the adoption of mandatory carbon offsetting programs and reminding the extension of the EU Emission Trading Scheme to aviation, literature findings demonstrated that systems vaulted at pricing emissions have effectively lowered industries' emission intensities, demonstrating their potential as effective means to mitigate climate change (Colmer, Martin, Muûls, & Wagner, 2023). Moreover, many existing studies claim that the air transport sector can best deliver its sustainability objectives by implementing measures geared towards the industry's technological and operational profile, namely by employing more ecologically efficient alternative technologies, especially the implementation of fuel-saving practices, sustainable aviation fuel (SAF), next-generation aircraft, and brand-new quieter and more fuel-efficient aircraft engines (Agarwal, 2009)(Ficca, Marulo, & Sollo, 2023). In addition to operational and technological enhancements, airline undertakings can consider employing carbon offsetting programs in their sustainability strategies, commonly known as voluntary carbon offsetting (VCO) programs. These programs provide an immediate solution to compensate for air travel environmental impacts. Specifically, passengers can voluntary choose whether or not to pay extra for offsetting carbon emissions when acquiring their tickets. Several studies analyzed the consequence of voluntary carbon offsetting programs on consumers, arguing that a positive approach towards VCO may depend on different variables, based primarily on their sociodemographic attributes (i.e., age, gender, level of education, income), sense of responsibility, environmental beliefs and awareness, frequency of utilization of air transport, the relative credibility they put on the airline's sustainable behavior.

Concerning the effect of sociodemographic characteristics, most literature findings show that younger passengers and individuals with a higher level of education feel more responsible towards the environment and climate awareness, which positively influences their decisions and pushes them to offset emissions (B. W. Ritchie, Kemperman, & Dolnicar, 2021)(Zhang, Ritchie, Mair, & Driml, 2019)(Segerstedt & Grote, 2016). Furthermore, according to some studies, consumers prone to frequent travel by air demonstrate a lower level of consideration about offsetting emissions (B. W. Ritchie et al., 2021)(Rotaris, Giansoldati, & Scorrano, 2020), despite some literature findings highlighting the opposite (Akter, Brouwer, Brander, & Van Beukering, 2009). Thereby, the relationship between the frequency of taking flights and the positive response to VCO has been demonstrated to depend on the geographical context (country of provenance) and the nature of the flight (international or domestic flight). In particular, the literature highlights that passengers who feel responsible for aircraft emissions when taking a flight tend to respond positively to voluntary carbon offsetting measures, displaying their willingness to pay extra to compensate for emissions (Kantenbacher, Hanna, Cohen, Miller, & Scarles, 2018)(Sonnenschein & Smedby, 2019). Again, literature findings affirm that a passenger's environmental and climate awareness of the extent of emissions produced by a flight and its relative climate impacts positively affects his or her decision to offset emissions through VCO (Yohan Kim & Ko, 2016)(Ropret Homar & Knežević Cvelbar, 2024). Other studies highlight that passenger knowledge of the efficiency of carbon offsetting programs positively affects their behavior concerning VCO programs, encouraging them to offset emissions (Choi, Ritchie, & Fielding, 2016)(B. W. Ritchie et al., 2021). However, over the years and after the various refinements on policy tools and implementation of mandatory carbon offsetting programs, such as the EU ETS scheme and the CORSIA scheme, research has affirmed that a noteworthy share of respondents are more inclined to prefer mandatory schemes over voluntary ones (Sonnenschein & Mundaca, 2019)(Sonnenschein & Smedby, 2019). However, despite the high consensus among studies about consumers' preference for mandatory contributions, a recent study by Eslaminassab and Ehmer in 2021 claimed that a roughly equal share between respondents preferring voluntary programs and those favoring mandatory schemes, showing surprisingly a slightly bigger preference for voluntary contribution for carbon offsettings over mandatory ones (45% versus 42%) (Eslaminassab & Ehmer, 2021).

2.4 Airlines and Sustainability Reporting

Airlines companies, leading actors in providing passenger air transportation services and fostering economic and social development, are increasingly devoting themselves to embracing sustainability in their business practices to meet customers' sustainability demands and enhance their corporate reputation. As sustainability catches on, stakeholders are more aware of the carbon footprints of different economic sector activities, especially in airline companies, where aircraft are notably responsible for environmental concerns ranging from their complex pack of emissions impacting the climate to noise and air quality pollution (*Section 2.2*). Despite the costly nature of sustainability practices at the corporate level, airlines consider sustainability as an opportunity rather than a threat, capable of enabling innovation and enhancing their reputation and attractiveness in the long term.

Concerning the linkage between corporate reputation and sustainability, according to the literature, sustainability reporting shows a positive linkage with corporate reputation. As a result, positive engagement with the three sustainability pillars and adoption of sustainability practices will lead to a reputation enhancement for undertakings (Hult, Mena, Gonzalez-Perez, Lagerström, & Hult, 2018) and (Irfan, Hassan, & Hassan, 2018). Additionally, ac-

cording to further research, sustainability approaches keep showing their function as enablers for increasing reputation and boosting the competitive advantage of undertakings (Melo & Garrido-Morgado, 2012).
Hence, according to a literature review and as a response to the increasing awareness of sustainability concerns among stakeholders, incorporating sustainability in business practices results as one of the leading strategies for achieving a desirable level of reputation enhancement, higher competitive advantage, and increasing financial performance (Johnson, Ashoori, & Lee, 2018), and a solid degree of customer loyalty, especially in the long run.

Additionally, the growing harmonization in the European legislation landscape in sustainability disclosures and initiatives increasingly requires undertakings to incorporate socially responsible practices in their business. In particular, EU legislation currently requires a range of undertakings to disclose specific sustainability information and strategies from a double materiality perspective, as presented by the amendment to the Non-Financial Reporting Directive (NFRD), which extended the obligation to disclose sustainability information to a broader range of companies through the creation of the Corporate Sustainability Reporting Directive (CSRD), also creating simplified standards to fit them for SMEs. Overall, the literature findings support the theory that disclosure of sustainability matters and sustainability practices positively impact consumers' trust and perception of undertakings (Kim, 2019).

Accordingly, like all other sectors, airlines need to discharge their accountability and efforts towards sustainability challenges via sustainability reporting, displaying how they are taking concrete action in adopting innovative alternatives for reducing their carbon footprint and environmental impact to meet stakeholders' sustainability demands and how they are approaching sustainability risks and opportunities in their corporate management.

2.4.1 SASB Standards - Airlines Sustainability Accounting Standards

When designing their sustainability reports, in complement to the mandatory European Sustainability Reporting Standards (ESRS) required by the Corporate Sustainability Reporting Directive (CSRD), european companies falling under the scope of CSRD can flexibly choose different sustainability reporting standards, shaping the content of their reports accordingly (*Section 1.4.4*). Instead, non-European companies, not currently subjected to any regulatory framework on sustainability reporting matters as European ones, can freely draw their sustainability reports, implementing their preferred sustainability standards and frameworks.

Sustainability Accounting Standards Board (SASB) Standards Part of the IFRS's proposed sustainability reporting standards are the Sustainability Accounting Standards Board Standards (SASB Standards). The SASB standards, elaborated by the International Sustainability Standards Board (ISSB)[8], constitute 77 sector-specific standards subdivided according to the Sustainability Industry Classification System® (SICS®)[9]. ISSB, mainly focusing on the financial materiality dimension, emphasizes the importance of considering sustainability factors in investment decisions and the need for companies to adopt global standards to enhance comparability in information on sustainability-related risks and opportunities. Accordingly, SASB Standards permit undertakings, thanks to industry-specific standards designed for each industry sector, to deliver industry-based disclosures concerning sustainability-related risks and opportunities that could potentially affect the undertaking's cash flows, access to finance, or cost of capital over the short, medium, and long term (sasb.ifrs.org, 2024).

Investor-focused Standards In particular, SASB Standards classify for each of the 77 industries the most relevant sustainability-related issues to investment decisions. Notable investors are increasingly interested in how undertakings handle their sustainability risks and opportunities; for that reason, comparable and standardized data are essential to guide effectively their investment decisions. Consequently, SASB Standards result as a set of standards specifically designed for investors, enabling the assimilation of sustainability considerations into investment decisions across portfolios and asset classes globally (sasb.ifrs.org, 2024).

SASB Standards Structure Each one of the SASB Sector-specific Standards includes different elements:

1. **Industry description**, designed to guide undertakings to identify to which industry they belong according to their business model, associated activities, and other sector-specific characteristics in the given industry.

2. **Disclosure topics**, indicating the list of the most relevant sustainability-related risks or opportunities linked to the activities pursued by the selected industry.

[8] The International Sustainability Standards Board (ISSB) is a standard-setting body established on 3 November 2021 in Glasgow during the COP26. The ISSB, as a standard-setting body, is responsible for elaborating high-quality and global standards for sustainability disclosures, which are chiefly focused on financial materiality, that is, investors' and financial markets' needs. (Source: ifrs.org, 2024)

[9] SASB uses SICS® as a classification tool to categorize companies through an impact-focused methodology from a sustainability perspective. SICS differs from traditional classification systems by organizing companies into sectors and industries according to their business model, resource intensity, sustainability impacts, and sustainability innovation potential. (Source: sasb.ifrs.org, 2024)

3. **Metrics**, relating specific disclosure topics that have to be disclosed by undertakings according to their industry, aiming to provide useful information concerning an undertaking's performance for each disclosure topic.

4. **Technical Protocols**, providing technical advice and guidance regarding definitions, scope, implementation, and presentation of related metrics.

5. **Activity metrics**, quantifying a scale for undertaking-specific activities or operations; designed to be implemented accordingly with 3. **Metrics** to normalize data and simplify comparability.

Airlines: Sustainability Accounting Standards

Industry description According to SASB Airlines-specific Standards, companies belonging to the airline industry are intended to be all those undertakings supplying air transportation services globally for different purposes (e.g., leisure, holidays, business trips).

Business model Airlines companies encompass both commercial **full-service**, **low-cost**, and **regional** airlines.

- **Full-service carriers**, employing a hub-and-spoke model in their business, designing international routes within countries.
- **Low-cost carriers**, supplying fewer routes than full-service ones and basic service to their clients without fancy and non-essential features.
- **Regional carriers**, usually operating under and managed by full-service ones, expanding larger carriers' networks.

Associated activities and other sector-specific characteristics SASB Airlines Standards also indicate that some airlines can provide cargo services to generate extra profits. Additionally, undertakings belonging to the airline industry usually form partnerships or join alliances aimed at expanding their network's size, offering their clients access to international or less-served routes on different airlines under one single ticket.

Sustainability Disclosure Topics & Metrics The Airlines SASB Standards represent in Table 1 the most relevant sustainability-related topics considered by investors in their investment decisions for the airline industry, displaying for each row the relevant topic for disclosure, indicating:

- 1st column: the specific name of the sustainability-related topic;
- 2nd column: the associate metrics to use to measure or describe the sustainability-related topic;
- 3rd column: the category of information to which the topic pertains, that can be quantitative or qualitative (i.e., discussion and analysis);
- 4th column: the unit of measurement associated to the metric of the sustainability-related topic;
- 5th column: the associated code for each metric.

TOPIC	METRIC	CATEGORY	UNIT OF MEASURE	CODE
Greenhouse Gas Emissions	Gross global Scope 1 emissions	Quantitative	Metric tons (t) CO_2-e	TR-AL-110a.1
	Discussion of long- and short-term strategy or plan to manage Scope 1 emissions, emissions reduction targets, and an analysis of performance against those targets	Discussion and Analysis	n/a	TR-AL-110a.2
	(1) Total fuel consumed, (2) percentage alternative and (3) percentage sustainable	Quantitative	Gigajoules (GJ), Percentage (%)	TR-AL-110a.3
Labour Practices	Percentage of active workforce covered under collective bargaining agreements	Quantitative	Percentage (%)	TR-AL-310a.1
	(1) Number of work stoppages and (2) total days idle[1]	Quantitative	Number, Days idle	TR-AL-310a.2
Competitive Behaviour	Total amount of monetary losses as a result of legal proceedings associated with anti-competitive behaviour regulations[2]	Quantitative	Presentation currency	TR-AL-520a.1
Accident & Safety Management	Description of implementation and outcomes of a Safety Management System	Discussion and Analysis	n/a	TR-AL-540a.1
	Number of aviation accidents	Quantitative	Number	TR-AL-540a.2
	Number of governmental enforcement actions of aviation safety regulations	Quantitative	Number	TR-AL-540a.3

Table 1: Sustainability Disclosure Topics & Metrics. (Source: Sustainability Accounting Standards - Airlines, sasb.org)

After that, Table 2 represents activity metrics, which are metrics for airline-specific activities. Each row represents the specific activity metric, indicating:

- 1st column: the specific name of the activity metric;

- 2nd column: the category of information to which the activity metric pertains, in this case only quantitative.
- 3rd column: the unit of measurement associated to the specific activity metric;
- 4th column: the associated code for each activity metric.

ACTIVITY METRIC	CATEGORY	UNIT OF MEASURE	CODE
Available seat kilometres (ASK)[3]	Quantitative	ASK	TR-AL-000.A
Passenger load factor[4]	Quantitative	Rate	TR-AL-000.B
Revenue passenger kilometres (RPK)[5]	Quantitative	RPK	TR-AL-000.C
Revenue ton kilometres (RTK)[6]	Quantitative	RTK	TR-AL-000.D
Number of departures	Quantitative	Number	TR-AL-000.E
Average age of fleet	Quantitative	Years	TR-AL-000.F

Table 2: Activity Metrics. (Source: Sustainability Accounting Standards - Airlines, sasb.org)

For each of the sustainability-related topics indicated in the "Sustainability Disclosure Topics & Metrics" section, the Sustainability Accounting Standard of Airlines outlines a summary describing the reasoning behind the choice of the relative sustainability-related issue as a topic for disclosure for the airline industry. Concerning the "Metrics" part, the Standards provide the associated code (Table 1, 4th column) of what the undertaking shall specifically disclose for each specific metric indicated in Table 1, 2nd column. In particular, it consists of the technical protocols providing technical guidance concerning the implementation and presentation for each of the metrics indicated in Table 1, 2nd column.

2.5 EU Taxonomy Regulation and Aviation

2.5.1 EU Taxonomy: an introduction

Part of the ten key actions envisaged by the EU Action Plan on Sustainable Finance (introduced in *Section 1.2*) adopted by the European Commission in 2018 is the EU Taxonomy Regulation 2020/852/EU, denominated as a fundamental cornerstone of the EU's sustainable finance strategy. The following legislation, which entered into force in July 2020, provides an effective market transparency tool aimed at complying with the first goal of the Action Plan strategy, which consists of redirecting capital flows toward sustainable investments and projects, also aligned with the European Green Deal objectives by supporting the transition

to a low carbon economy. In particular, the EU Taxonomy functions as a classification mechanism for single economic activities to label them as "environmentally sustainable" according to compliance with specific criteria set out by the Regulation.
Article 1(2) of the Taxonomy requires the application of the Regulation in the following cases:

(a) measures adopted by Member States or by the Union setting out requirements for financial market participants or issuers concerning financial products or corporate bonds provided as environmentally sustainable;

(b) financial market participants providing financial products;

(c) undertakings subject to the obligation to publish a non-financial statement or a consolidated non-financial statement according to Directive 2013/34/EU (EC, 2020c).

According to Article 3 of Regulation 2020/852/EU, a single economic activity to be labeled as "environmentally sustainable " shall comply with four overarching criteria:

(a) it shall **substantially contribute** to one or more of the environmental objectives set out by Article 9 of this Regulation;

(b) it shall **do not significant harm (DNSH)** any of the other five environmental objectives listed by Article 9 of this Regulation, according to criteria further specified by Article 17 of this Regulation;

(c) it shall comply with **minimum social and governance safeguards**[10] provided by Article 18 of this Regulation; and

(d) it shall comply with **technical screening criteria** settled by the Commission according to Article 10 (3), 11(3), 12(2), 13(2), 14(2) or 15(2), defined for each of the six environemntal objectives of Article 9 (EC, 2020c).

As mentioned above, Article 9 of Regulation 2020/852/EU sets out the six environmental objectives crucial to this legislation.
"For the purposes of this Regulation, the following shall be environmental objectives:

(a) climate change mitigation;

(b) climate change adaptation;

[10]Alignment with "OECD Guidelines for Multinational Enterprises and the UN Guiding Principles on Business and Human Rights, including the principles and rights set out in the eight fundamental conventions identified in the Declaration of the International Labour Organisation on Fundamental Principles and Rights at Work and the International Bill of Human Rights". (Source: Article 18 of Regulation 2020/852/EU).

(c) the sustainable use and protection of water and marine resources;

(d) the transition to a circular economy;

(e) pollution prevention and control;

(f) the protection and restoration of biodiversity and ecosystems."

Regulation (EU) 2020/852 of the European Parliament and the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (EC, 2020c)

According to the Taxonomy classification system and based on political agreement, three types of economic activities can be labeled as environmentally sustainable:

- Activities **contributing substantially** to at least one of the Article 9 six environmental objectives.
- **Transition activities**, which are not currently capable of satisfying technological and economic criteria to be classified as feasible low-carbon alternatives but that support the transition towards a climate-neutral economy compatible with the Paris Agreement 1.5°C temperature goal.
- **Enabling activities**, which encourage other activities to substantially contribute to one or more of the environmental objectives, and where the former activity:
  - does not lead to lock-in in assets that undermine long-term environmental goals, considering the economic lifetime of those assets;
  - has a substantial positive environmental impact based on lifecycle considerations.

  Power generation activities derived from solid fossil fuels are excluded from being eligible (*Questions and Answers: political agreement on an EU-wide classification system for sustainable investments (Taxonomy)*, 2019).

Article 8 Disclosures Delegated Act Furthermore, Article 8 of this Regulation requires undertakings falling under the scope of the Directive (EU) 2022/2464 (i.e., Corporate Sustainability Reporting Directive), which are subject to the obligation of publishing non-financial information, to attach relevant information and specific key performance indicators (KPIs) concerning the extent to which the undertaking's activities results related to economic activities labeled as environmentally sustainable under Article 3 criteria of such Regulation

2020/852/EU to their non-financial reports.
Article 8(4) specifies the Commission's adoption of a Delegated Act, whose function is to specify the content and presentation of the information prescribed by the previous paragraphs and the fitting methodology to be applied to comply with the disclosure requirements.
In particular, as further prescribed by the Disclosure Delegated Act supplementing Regulation 2020/852/EU adopted by the Commission (i.e., Commission Delegated Regulation (EU) 2021/2178 of 6 July 2021), financial and non-financial undertakings are required to perform specific disclosures according to their nature, specifically:

Non-financial undertakings shall disclose information concerning:

(a) proportion of their **turnover** (Turnover KPI) derived from products or services related to economic activities labeled as environmentally sustainable according to Article 3 criteria of Regulation 2020/852/EU;

(b) proportion of their **capital expenditure** (CapEx KPI) and **operating expenditure** (OpEx KPI) connected to assets or processes related to economic activities labeled as environmentally sustainable according to Article 3 criteria of Regulation 2020/852/EU (EC, 2021b).

Asset managers shall disclose information concerning the proportion of their managed investments in taxonomy-aligned economic activities (i.e., compliant with Article 3 criteria of Regulation 2020/852/EU) over the total value of all assets under management (AuM), denominated as "Green Investment Ratio (GIR)" (EC, 2021b).

Financial undertakings shall disclose information concerning the proportion of their assets financing and invested in taxonomy-aligned economic activities (i.e., compliant with Article 3 criteria of Regulation 2020/852/EU) over their total covered asset, denominated as "Green Asset Ratio (GAR)", a percentage of "sustainable loans" (EC, 2021b).

The main benefit of adopting the Article 8 Disclosures Delegated Act lies in its functionality, which aims to eliminate some of the principal market failures tied to sustainable finance. In particular, the provision seeks to foster transparency within the European market, minimize greenwashing, and work as an enhancement reputational tool for financial and non-financial entities. The following Act also accomplishes the EU Action Plan on Sustainable Finance objectives, creating a landing place for green finance and stimulating the development of green financial products (*FAQ: What is the EU Taxonomy Article 8 delegated act and how will it work in practice?*, 2021).

Delegated Regulation (EU) 2021/2139 Supplementing the EU Taxonomy Regulation 2020/852/EU, the Delegated Regulation (EU) 2021/2139 designates the technical screening criteria aimed at ascertaining the conditions under which an economic activity contributes substantially to climate change mitigation or climate change adaptation objectives and determining according to which criteria such economic activity is deemed to not significantly harm any of the other five environmental objectives listed in Article 9 of Regulation 2020/852/EU (EC, 2021a).
The Delegated Regulation provides a vast list of economic activities, defining for each activity the description of the latter (i.e., description of the activity), its relative technical screening criteria for assessing the substantial contribution to the first two environmental objectives (i.e., climate change mitigation and climate change adaptation objectives), and the "do not significantly harm (DNSH)" criteria for the other five outstanding environmental objectives. In particular:

- **Annex I** of Delegated Regulation (EU) 2021/2139 sets out the technical screening criteria under which an economic activity substantially contributes to the **climate change mitigation** environmental objective and the relative "do not significant harm (DNSH)" criteria for the remaining five environmental objectives set out by Article 9 of Regulation 2020/852/EU (EC, 2021a);
- **Annex II** of Delegated Regulation (EU) 2021/2139 sets out the technical screening criteria under which an economic activity substantially contributes to the **climate change adaptation** environmental objective and the relative "do not significant harm (DNSH)" criteria for the remaining five environmental objectives set out by Article 9 of Regulation 2020/852/EU (EC, 2021a);

2.5.2 The Delegated Regulation (EU) 2023/2485 of 27 June 2023

Considering the six environmental objectives listed by Article 9 of Regulation 2020/852/EU, the European Commission acknowledges the paramount role of the aviation industry as a transitional activity in addressing environmental concerns in the transportation sector. In particular, the European Commission believed that the aviation sector could significantly reduce carbon emissions through significant sustainability efforts, contributing substantially, according to Article 3 criterium, to climate change mitigation objectives.
In light of the fact of the non-complete coverage of all economic activities by the Delegated Regulation (EU) 2021/2139 (Climate Delegated Act)[11] and of the need to consider the aviation sector as a leading participant in addressing climate concerns relative to environmental

[11] Commission Delegated Regulation (EU) 2023/2485 of 27 June 2023 point (3).

objectives listed by Article 9 of the EU Taxonomy Regulation, the European Commission amended the Delegated Regulation (EU) 2021/2139 by adding additional technical screening criteria for certain economic activities that may be able to substantially contribute to the climate change mitigation and adaptation objectives (EC, 2023).
According to point (3), stressed by the new Delegated Regulation (EU) 2023/2485, "additional economic activities that contribute substantially to climate change mitigation cover largely the transport sector and its value chain" (EC, 2023) may be included in Annex I listed activities,, thus encompassing the air transportation sector and its related activities.
In particular, Annex I of the Delegated Regulation (EU) 2023/2485 recognizes the following aviation-related economic activities as transition activities falling within the scope of the EU Taxonomy Regulation application:

- **Manufacturing of aircraft** (Section 3.21., Delegated Regulation (EU) 2023/2485)
- **Leasing of aircraft** (Section 6.18., Delegated Regulation (EU) 2023/2485)
- **Passenger and freight air transport** (Section 6.19., Delegated Regulation (EU) 2023/2485)
- **Air transport ground handling operations** (Section 6.20., Delegated Regulation (EU) 2023/2485)

Concerning this information, we will analyze Section 6.18. and 6.19. of this Delegated Regulation closely, as being more closely involved with the airline industry.

3.21. Manufacturing of aircraft According to the former provision, "manufacturing of aircraft" consists of the "manufacture, repair, maintenance, overhaul, retrofitting, design, repurposing and upgrade of aircraft and aircraft parts and equipment" (EC, 2023) activities.

NACE codes All of the above-mentioned economic activities belong to the NACE codes C30.3 and C33.16 according to the classification stated by Regulation (EC) No 1893/2006.

6.18. Leasing of aircraft "Leasing of aircraft" encompasses the "renting and leasing of aircraft parts and equipment" (EC, 2023) economic activities.

NACE codes The former economic activity could be related to NACE code N77.35, referring to aircraft leasing operations "without operator", that is, dry operating leasing (i.e., aircraft-specific leasing without ancillary services, such as insurance, equipment, maintenance, and ground assistance), encompassing also leasing operations of aircraft engines (E. Giddings & Carrier, 2023).

Substantial contribution to climate change mitigation The provision then provides a list of aircraft subject to leasing operations that can substantially contribute to climate change mitigation, mentioning, among others, "aircraft with zero direct (tailpipe) CO_2 emissions".

"Aircraft with zero direct (tailpipe) CO_2 emissions" consists of new technology aircraft having zero direct CO_2 emissions derived from their exhaust pipe (e.g., hydrogen or battery-powered aircraft); according to such technical screening criteria, a leasing operation involving this type of new technology aircraft will be labeled as an environmentally sustainable economic activity according to EU Taxonomy Regulation 2020/852/EU and not as a transitional activity (E. Giddings & Carrier, 2023). Nevertheless, at present times, this type of aircraft still needs to be operated and commercialized. Considering this, aircraft leasing operations involving other aircraft types mentioned by the technical screening criteria fulfilling the "substantial contribution to climate change mitigation" criteria would result in a transitional activity, provided that they comply with the further criteria set out by the provision.

In particular, the Delegated Regulation mentions leasing operations employing "aircraft delivered before 11 December 2023" compliant with technical screening criteria requiring compliance with the replacement ratio[12] threshold and, additionally, for aircraft until 31 December 2027:

- to have a take-off mass between 5.7 t and 60 t and a certified metric value of CO_2 emissions of at least 11% (i.e., percentage related to the aircraft's maximum take-off weight) lower than the International Civil Aviation Organization (ICAO) New Type limit[13] (EC, 2023);
- to have a take-off mass between 60 t and 150 t and a certified metric value of CO_2 emissions of at least 2% lower than the International Civil Aviation Organization (ICAO) New Type limit (EC, 2023);
- to have a take-off mass greater than 150 t and a certified metric value of CO_2 emissions of at least 1.5% lower than the International Civil Aviation Organization (ICAO) New Type limit (EC, 2023).

Furthermore, after 31 December 2027, from 1 January 2028 until 31 December 2032, aircraft will need to meet the technical screening criteria mentioned above, plus they shall be certified to operate under 100% mixture of sustainable aviation fuels (SAFs) (EC, 2023).

[12] The replacement ratio introduced by the Delegated Regulation consists of the number of aircraft drawn permanently from utilization over the total number of aircraft delivered globally in the last 10-year period.

[13] The parameter is specified in Annex 16 to the Convention on International Civil Aviation, Environmental Protection, Volume III, CO_2 Certification Requirement, First Edition March 2017.

Additionally, the Delegated Regulation states that for "aircraft delivered after 11 December 2023", complying with the same technical screening criteria established for "aircraft delivered before 31 December 2023", a non-compliant aircraft in the existing fleet having at least 80% of the maximum take-off weight of the compliant aircraft shall be permanently drawn from the fleet or employment (i.e., the aircraft shall be either permanently disposed of service by selling the aircraft to a third party, keeping the replacement ratio invariant, or disposed definitely of the global fleet, reducing the replacement ratio) within six months of delivery of the new compliant aircraft according to the above-mentioned technical screening criteria (EC, 2023). Furthermore, the Regulator emphasizes compliance with an additional criterion applicable from 1 January 2030 applicable to aircraft meeting the abovementioned criteria operating with a minimum share equal to 15% of sustainable aviation fuel (SAF) (EC, 2023). In particular, those aircraft will have to augment by 2% points the share of SAF each year from 2030 onwards (EC, 2023).

The Delegated Regulation then defines the computation mechanism for the share of Sustainable Aviation Fuel (SAF), which should be calculated as the amount of SAF used at the fleet level over the total aviation fuel used for fueling the compliant aircraft[14] (EC, 2023).

$$\% \text{ of SAF} = \frac{\text{Tonnes of SAF purchased at fleet level}}{\text{Total aviation fuel used by compliant aircraft}} \times 100 \tag{2}$$

Do not significant harm (DNSH) The "do not significant harm (DNSH)" criteria for such economic activity then requires aircraft leasing operations not to produce significant damage to any of the other five remaining environmental objectives set out by Article 9 of Regulation 2020/852/EU, providing an incentive to comply with the replacement ratio by removing completely from global fleet non-compliant aircraft, provided that such removal is compliant with DNSH criteria (4) "Transition to a circular economy", requiring the compliance with the EU waste regulation principles. Then, in criteria (5) "Pollution prevention and control" criteria, the Regulation requires the activity to respect specific noise thresholds established by Amendment 13 of Volume I (Noise), Chapter 14 of Annex 16, Chicago Convention (EC, 2023).

6.19. Passenger and freight air transport The section "Passenger and freight air transport" encloses all the economic activities consisting of "purchase, financing, and operation of aircraft including transport of passengers and goods" (EC, 2023), excluding leasing operations already mentioned in Section 6.18 of this Delegated Regulation.

[14]Compliant aircraft refers to aircraft respecting the requirement of the certified metric value of CO_2 emissions below the ICAO standard limit.

NACE codes The provision then attributes to the economic activities their relative NACE codes, namely H51.1 and H52.21, specifically relating to "renting of air transport equipment with operator", the opposite of dry leasing, then comprising all the ancillary services that dry leasing is missing (E. Giddings & Carrier, 2023).

Substantial contribution Then, as under Section 6.18, if one of the above-mentioned economic activities employs "aircraft with zero direct (tailpipe) CO_2 emissions", such activity shall not be considered a transitional activity but rather a taxonomy-aligned economic activity according to EU Taxonomy Regulation.
As for section 6.18, all the other listed aircraft fulfilling the substantial contribution criteria to climate change mitigation shall be considered transitional activities when complying with the remaining Delegated Regulation's technical screening criteria (E. Giddings & Carrier, 2023).
Despite some differences, the criteria apply to aircraft employed in "passenger and freight air transport" economic activities similar to "leasing of aircraft" activities. In particular, the requirement to meet the certified level of CO_2 emission below the ICAO New type standard threshold applies until 31 December 2029 rather than the 31 December 2027 date provided for the leasing operation activities. Additionally, aircraft operating in "passenger and freight air transport" activities must comply with an additional criterion concerning those aircraft starting their operation in 2022 with a share equal to 5% of sustainable aviation fuel (SAF). In particular, those aircraft will have to augment by 2% points the share of SAF each year (EC, 2023).

Do not significant harm (DNSH) The "do not significant harm (DNSH)" criteria established for "passenger and freight air transport" economic activities on the remaining EU Taxonomy's Article 9 five environmental objectives result in equal to the ones furnished for "leasing of aircraft" activities.

6.20. Air transport ground handling operations The provision establishes that the "air transport ground handling operations" section shall include all the economic activities entailing "manufacture, repair, maintenance, overhaul, retrofitting, design, repurposing and upgrade, purchase, financing, renting, leasing and operation of equipment and service activities incidental to air transportation (ground handling), including ground services at airports and cargo handling, including loading and unloading of goods from aircraft" (EC, 2023) operations. This section excludes the vehicles transporting passengers and crew and refueling aircraft inside the airport area.

NACE codes The Delegated Regulation attributes H52.23, H52.24, and H52.29 NACE codes to the operations falling under the "air transport ground handling operations" economic activity (EC, 2023).

2.6 Decarbonization Approaches in the Aviation Industry

Given the recorded increase of at least 5% per year in commercial passenger air transport between 2000 and 2019 and the concrete amount of direct CO_2 emissions, displaying an average increment of 2% per year, the air transport sector is constantly endeavoring to intensify its efforts against sustainability challenges to ensure the transition to a low carbon economy and the achievement of the ambitious ICAO's decarbonization goal by 2050 (Cazzola & Lassman, 2021). Moreover, in terms of actions, the air transport sector has already implemented significant measures, reducing its energy intensity at an average pace of 2.8% yearly since 2000, demonstrating enhancements in average fuel efficiency per revenue tonne kilometer (RTK) equivalent traveled for 1.8% (IEA, 2023a), attributed primarily to enhancements from the operational perspective and technological innovations concerning the technical profile of aircraft (e.g., increasing load capacity and the number of passenger seats, lowering energy use per aircraft km by improving energy efficiency and reducing fuel usage by introducing new aircraft engines) (Cazzola & Lassman, 2021). However, despite its considerable efforts in mitigating emissions, the aviation industry failed to match the pace of demand expansion, which surged at an average yearly rate exceeding 5% from 2010 to 2019 (IEA, 2023a), strongly recovering after the COVID-induced crisis. Thereby, air traffic still holds its title as one of the most impacting transport modes from an energy-intensity perspective. Additionally, despite the positive effects of long-distance travel on society and the economy, it has, as mentioned in *Section 2.2*, several negative environmental impacts other than CO_2 emissions, enlarging the ecological footprint of the air transport industry.

For these reasons, policymakers, international agencies, governments, airlines, airports, and other air transport industry stakeholders are currently developing and adopting mitigation actions, such as policy and taxation tools, new technologies, and sustainability practices, which their blending ensure the transition to a more sustainable and low-carbon economy, supporting the achievement of the ICAO's long-term aspirational goal (LTAG) of net-zero CO_2 emissions by 2050.

In this Section, we will analyze what has been done or planned to be done in the policy context, from the technological and operational perspective, and sustainability practices implemented in the air transport sector to address today's sustainability challenges.

2.6.1 Policy instruments

Command-and-control policy Command-and-control policies are among the main instruments used in environmental policies. This type of policy consists of legislation or instruments either setting out standards and rules directly applicable and backed up by sanctionary measures in case of non-compliance ("negative") or setting emission targets and requiring the implementation of specific equipment by polluters ("positive").
In the context of air transport, greenhouse gas emissions originating from aircraft could be limited by setting specific aircraft technological standards aimed at reducing emissions. In particular, since 1981, the International Civil Aviation Organization (ICAO) has implemented specific stringency standards functioning as recommendations (i.e., not mandatory) for pollutants concerning the effects of emissions on air quality during aircraft landing-take-off cycles. Annex 16, Vol. III (Environmental Protection) to the Convention on International Civil Aviation first introduced standards and certification requirements for CO_2 emissions in 2017[15]. These rules, applied in March 2017, affect aircraft constructed from 2020 and those already in construction from 2023. Furthermore, starting in 2028, such standards will enforce the dismission of non-compliant aircraft production (ICAO, 2017). Notably, aircraft weight affects fuel consumption according to the different flight phases. To comply with these peculiar characteristics, the ICAO's rules set a complex set of standards, adapting to different flight phases and considering the aircraft payload, range, and floor space available (Fichert et al., 2020b).

However, concerning the aviation sector, other policy instruments, such as market-based measures, have been demonstrated to be more economically efficient than the above-described command-and-control policies. The effectiveness of market-based measures lies in their capacity to ensure a sort of "environmental target" (i.e., a cap on the amount of CO_2 in the case of the EU ETS scheme), pricing emissions directly (e.g., by establishing the carbon market and the trade of allowances) and indirectly (e.g., by incentivizing aircraft operators to implement operational improvements aimed at reducing emissions and reducing negative externalities) (Maertens, Grimme, & Scheelhaase, 2020). Two of the predominant market-based measures established are the European Emission Trading System on the aviation sector (developed by EU pending the global measure by ICAO) and the global carbon offsetting program elaborated by ICAO, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) scheme. The following paragraphs of this sub-section will further

[15] The following requirements are the ones mentioned in the Delegated Regulation (EU) 2023/2485 of the EU Taxonomy setting technical screening criteria for specific air transport sector economic activities to be classified as environmentally sustainable transition activities.

describe the market-based measures mentioned above.

Taxes Governments can implement taxation policies in the air transport industry through different taxation tools:

- taxes on air transport service (e.g., Value Added Taxes (VAT) and specific "ticket taxes");
- taxes on fuel, which, due to the direct proportionality between burning fuel and CO_2 emissions, tax fuels work, in practice, as a tax on carbon emissions; and
- taxes on emissions.

Taxes on air transportation service Taxes on airline tickets are the burden of passengers acquiring the ticket. The amount of the tax varies according to several factors, such as the flight distance and class of travel, which determine the final price of the ticket accordingly. Airline ticket taxes currently encompass more than 50% of the EU air transport market. However, this kind of taxation is a standard measure undertaken by most aviation markets globally, chiefly thanks to the simplicity with which these taxes can be managed and their effectiveness in raising substantial funds (Delft et al., 2019).

Fuel taxes Due to the high correlation between fuel consumption and CO_2 emissions (i.e., the higher the fuel consumption, the higher the extent of CO_2 emissions emitted), a fuel tax in the aviation sector would function the same as a carbon tax. European countries have the prerogative to enact fuel taxes within the aviation industry as per Directive 2003/96/EC on energy taxation. Nevertheless, among these nations, the Netherlands was the sole European country executing a fuel tax on domestic flights in 2005, subsequently abolished in 2012. This decision was primarily motivated by concerns regarding the potential adverse repercussions on the Dutch economy and the urge to maintain a competitive position in the global aviation industry. Accordingly, the effect of a fuel tax in the European landscape would result in a decrease in demand, causing an increase in fuel price in the immediate short run, enabling airlines to adopt fuel-efficient practices and technologies in the long run (i.e., employment of fuel-efficient aircraft in their fleets). Compared to the fluctuating price of allowances established in the EU Carbon Market of the EU Emission Trading Scheme (further explained below), taxes would result in more stable prices, reducing airline uncertainty when it comes to designing and investing in long-term projects (Fichert, Forsyth, & Niemeier, 2020a). However, according to several studies, a fuel tax in aviation should be introduced upon establishing an international agreement to avoid producing significant distortions of competition between airlines from different countries (Knorr & Eisenkopf, 2020). If a fuel tax were implemented only in some countries, airlines located in countries where taxation is not applied would face lower costs, creating, hence, distortions in competition between those airlines bearing the burden of fuel taxation.

Taxes on emissions Addressing emissions beyond CO_2, such as NO_x, through a taxation framework presents considerable challenges due to the complex nature of their climate-related impacts. The effectiveness of such a scheme results in a winding path because the environmental consequences of NO_x emissions, like other non-CO_2 emissions stemming from air traffic, are heavily influenced by dynamic factors such as flight altitudes, geographical locations, and meteorological conditions, which exhibit considerable variability (Fichert et al., 2020a).

EU Emission Trading Schemes (ETS) The European Emission Trading Scheme (ETS), launched in 2005, is the market-based measure (MBM) implemented by Europe to fight climate change and reduce the extent of greenhouse gas emissions cost-efficiently, consistent with the Paris Agreement and EU climate objectives. Nowadays, the EU ETS demonstrated to contributing for the reduction of emissions from power and industry plants by 37% from 2005 until today.
The legislation originally designed to regulate the EU ETS mechanism is Directive 2003/87/EC (EC, 2003) (ETS Directive), which was subject to several revisions over the past years, mainly due to the ongoing variations of the EU's climate target. By following the European Climate Law, the EU ETS system commits itself to reducing net emissions by at least 55% by 2030 compared to 1990 cost-efficiently, aiming to attain climate neutrality in the European Union by 2050 (EC, 2024b). Nowadays, the EU ETS is the most extensive policy instrument applied to the air transport sector.

Functioning of EU ETS The EU ETS consists of the establishment of a "cap and trade" system, setting a target/limit (the "cap", an allowable maximum amount) for the total allowable amount of greenhouse gases that each of the installations and aircraft operators under the system can emit. In particular, the ETS system covers greenhouse gas emissions consituted of carbon dioxide (CO_2), nitrous oxide (N_2O), and perfluorocarbons (PCFs).
The ETS functions by freely issuing permits or allowances (i.e., EU Allowances or EUAs) to industry plants and aircraft operators, allowing them to emit until the yearly allowable maximum emission limit is reached.
The scheme establishes thus the EU Carbon Market, within which firms can trade their

permits if they produce emissions lower than the cap amount or buy new ones if they exceed it. In particular, one permit allows the emission of an amount of CO_2eq equal to one tonne. The cap set by the ETS is then reduced yearly to ensure compliance with the EU's climate target, effectively reducing emissions over time. Accordingly, operators generating significant emissions and emitting for amounts above the cap set would need further permits to account for additional emissions entirely; otherwise, heavy fines could be imposed.
As mentioned above, allowances can be obtained in different ways; they can be issued to firms for free, sold at their market price, or traded between firms in the EU Carbon Market. However, most commonly, allowances are distributed for free primarily to emissions-producing firms and upstream energy suppliers.

Scarcity of allowances Like conventional markets, the EU carbon market operates similarly, whereby the annual reduction in the emissions "cap" dictates the scarcity of allowances, thus ensuring a stable or increasing market price for these allowances. This pricing mechanism is designed to encourage entities to reduce their emissions, contingent upon the condition that emission reduction costs remain below the allowances price determined by the EU carbon market. Consequently, entities encountering high costs in implementing emission reduction measures may purchase permits to keep emitting. In contrast, those entities facing lower costs in emission reduction may choose to forgo purchasing permits or already possessed ones, selling them to those entities in the opposite situation, implementing thus emission reduction practices, and reducing their emissions accordingly (Fichert et al., 2020b).

Aviation industry and EU ETS The historical background behind the decision for the European Union to adopt its own aviation market-based measure dates back to 1997, when the Kyoto Protocol highlighted the necessity of including airports and domestic aviation CO_2 emissions into its climate change policy, mandating ICAO for the management of international air transport emissions instead, which after consulting the IPCC and obtained a specific assessment concerning the aviation impact on climate change ("Aviation and the Global Atmosphere" Report, 1999). Since then, ICAO struggled to find a standard global market-based measure against CO_2 emissions. The European Union, pending action from ICAO, decided to introduce its own market-based measure to be applied to the air transport industry. Accordingly, due to increasing environmental concerns related to both CO_2 and non-CO_2 emissions generated by aircraft engines, the rapid and extensive growth of air traffic, and the failure of ICAO to adopt a global measure for emission reductions timely, the European Union decided to include the air transport industry in its already in force market-based measure in July 2008, starting its application from 2012. The EU adopted the

Directive ruling out the specifications concerning the aviation industry's inclusion in the EU ETS scheme in January 2009, expecting all Member States to transpose its provisions by the end of 2009. To cooperate with the ICAO, pending the elaboration of their global measure, the EU ETS legislation on the aviation industry has undergone at least three amendments from 2012 to 2023.

Original scope Most notably, the European Union originally designed its ETS scheme to be applied to all aircraft operators performing flights from and to European Union airports, thus including flights from non-European countries to European ones and vice versa. However, many countries outside the European Union (e.g., the United States, China, and Russia) increasingly opposed the EU ETS scheme between 2011 and 2012 before the latter became officially effective (Lan, 2011)(CMW, 2017). In response to these oppositions, the EU, through Regulation 421/2014, adopted in April 2014, decided to reduce the geographical scope of its market-based measure, including only flights occurring in the European Economic Area (EEA), that is, intra-EU flights. Most notably, the European Union originally designed its ETS scheme to be applied to all aircraft operators performing flights from and to European Union airports, thus including flights from non-European countries to European ones and vice versa (Morrell, 2020).

Reduced geographical scope However, following opposition from many countries outside the European Union (e.g., the United States, China, and Russia) to the EU ETS scheme between 2011 and 2012 (Bartels, 2012), the EU decided to reduce the geographical scope of its market-based measure in 2013. In particular, the EU adopted Regulation 421/2014 in April 2014 in response to the increasing opposition to the scheme, specifying the new scaled-down geographical scope by incorporating the amendment in the original Directive 2003/87/EC. The new EU ETS reduced scope includes only flights occurring in the European Economic Area (EEA), that is, intra-EU flights. This amendment was originally intended to be effective until 2016, waiting for the ICAO's finalization of its global market-based measure, then extended from 2017 onwards after the 2016 ICAO announcement of its global carbon-offsetting scheme for the air transport industry (i.e., CORSIA scheme, further explained in the next paragraph), waiting for further international developments concerning the latter.

EU ETS and aviation: established parameters Despite the EU ETS scheme specifies its coverage for carbon dioxide (CO_2), nitrous oxide (N_2O), and perfluorocarbons (PCFs) emissions, in the case of the air transport sector, its coverage is limited to CO_2 emissions

only.
Concerning the cap set on air transport emissions, in 2012, the emissions limit (i.e., cap) for aircraft operators (i.e., airlines) was initially set to 97% of average greenhouse gases emitted from 2004 to 2006 (2004-2006 baseline), then reduced to 95% of the baseline from 2013 to 2020.
The EU ETS, intended to apply to airlines operating intra-EU flights, indicates some exemptions falling outside its scope of application. In particular, the scheme does not apply to smaller aircraft emitting less than 10,000 tonnes of CO_2 annually and to military, training, and rescue flights.
The European scheme prescribes freely allocating 82% of EU allowances to aircraft operators based on an efficiency benchmark assessment. Instead, the remaining 15% of allowances are intended to be auctioned, and the other 3% is distributed to fast-growing and emergent aircraft operators (EU, 2024). The free allocation of allowances based on an efficiency benchmark assessment primarily aims to reward airlines that already demonstrate high commitment to reducing their CO_2 emissions through increased operational efficiency, penalizing instead those operating less efficiently in emission reduction efforts (Morrell, 2020). The benchmark, in particular, is thus based on airline efficiency in transporting passengers and cargo. According to the EU ETS mechanism, aircraft operators wishing to obtain free allowances must submit their verified tonne-kilometer data for 2010. From 2012 to 2020, according to the efficiency benchmark's assessment computations, a single airline should receive 0.6422 allowances per 1,000 tonne-kilometers flown.

Impact of EU ETS on aviation In light of that, airlines falling under the EU ETS application must obtain allowances whenever they generate extra emissions higher than the baseline cap, facing extra costs and potentially decreasing profitability. However, most of the studies on the effects of the EU ETS implementation on airlines profitability and air traffic demand were conducted based on the original version before the reduced geographical scope was applied. In particular, several of these studies pointed out that lower profits may lead airline companies to transmit those extra costs to consumers, potentially affecting, in turn, demand for airline services or, in the best-case scenario, finding alternatives to new emission reduction measures; thus, the EU ETS mechanism has the potential to stimulate technological innovation in the long term. Hence, the implications of both changing demand and introducing new emission reduction methods might lead to fewer emissions. Considering the first case, when consumers face higher-than-expected prices for airline services, they will decrease their demand for those services in accordance, leading to fewer scheduled flights, provided that the decrease in demand is significant enough to substantially reduce the load factor (i.e., seats occupied in one aircraft) in a discrete amount of flights (Anger & Köhler, 2010). However, studies and research conducted prior to the application of the ETS scheme to the air transport sector and when carbon prices were still significantly lower concluded that extending the application of EU ETS to aircraft operators should not lead to significant variations in the demand for airline's services by 2020 (Ernst, 2007)(Boon, Davidson, Faber, & Van Velzen, 2007), thus not impacting airlines profitability significantly.

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

The Carbon Offsetting Scheme for International Aviation (CORSIA) is one of the first greenhouse gas mitigation measures designed for the air transport industry aimed at decreasing carbon emissions in international flights.

The reaching of the agreement on such a program followed a historical background mentioned before dating back to 1997, when the Kyoto Protocol declared the inclusion of airports and domestic aviation CO_2 emissions into its climate change policy, excluding however international air transport emissions (CO_2 and non-CO_2 emissions). Instead, the responsibility for international air transport emissions was delegated to the International Civil Aviation Organization (ICAO) in a joint agreement between governments. After the occurrence of such a mandate, ICAO consulted the International Panel on Climate Change (IPCC), requesting the performance of an assessment on the impact of aviation on climate change, leading to the elaboration of the "Aviation and the Global Atmosphere" IPCC report in 1999, also examining policies and measures feasible to reduce greenhouse gas emissions. The IPCC 1999 report concluded that international aviation represented roughly 65% of global aviation fuel consumption, accountable for approximately 1.3% of global CO_2 (Penner et al., 1999).

After almost two decades, in October 2016, the 191 ICAO's Member States jointly agreed to establish Assembly Resolution A39-3, which decided to set up a mitigation measure for greenhouse gas emissions in the air transport sector, making a significant step in addressing climate change and designating the CORSIA program. The introduction of the CORSIA scheme constitutes one complementary step among other measures towards achieving ICAO's environmental objectives of reaching carbon-neutral growth.

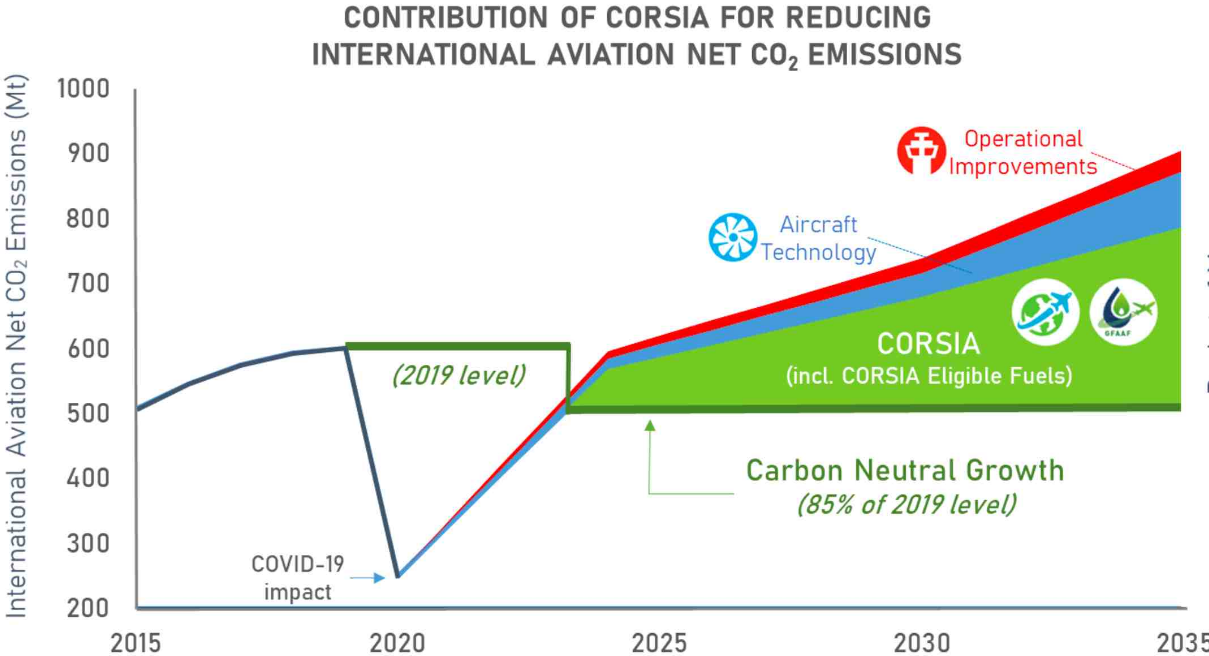

Figure 11: Estimated Contribution of Measures For Reducing International Aviation Net CO_2 emissions. (Source: ICAO website)

CORSIA scheme, regarded as a major international milestone towards greener aviation (Maertens et al., 2020), functions as a global compensation scheme and market-based measure (MBM, e.g., levies and emissions trading systems), in which airlines and other aircraft operators from different countries worldwide commit to compensating for higher CO_2 emission increases than the ones registered in the 2019-2020 pre-COVID period.

Establishing and pursuing the CORSIA approach ensures the stabilization of CO_2 emissions in the long run by implementing progress in aircraft technologies, operational improvements, and sustainable aviation fuel (i.e., CORSIA's eligible fuels), as Figure 11 illustrates. In the case of the inability of participating States to reduce their excess of CO_2 emissions through the abovelisted methods and measures, they can rely on eligible emissions units (i.e., "carbon credits", issued by greenhouse gas reduction projects) available in the Aviation Carbon Exchange (ACE) (i.e., entralized marketplace for CORSIA eligible emission units (IATA, 2024a)), which can be acquired to compensate for post-2020 increases in emissions compared to the 2020 baseline (as in the EU ETS mentioned before). Concerning the emission limit airlines have to refer to, the ICAO, during its 41st Assembly (2022), set the CORSIA's baseline to 85% of 2019 emissions (see Figure 11) from 2024 until 2035 (IATA, 2023b).

Accordingly, airlines incurring higher costs for reducing emissions will choose to offset their emissions by acquiring carbon credits. On the other hand, airlines that find cheaper costs

to implement carbon emission reduction measures will choose to sell their carbon credits to airlines in the opposite situation.
The CORSIA mechanism's implementation is structured in three distinct phases:

- **pilot phase**, from 2021 to 2023;
- **first phase**, from 2024 to 2026; and
- **second phase**, from 2027 to 2035.

Pilot phase The pilot phase is the first voluntary phase. Thus, in the pilot phase, States can voluntarily declare their will to participate in the scheme; as of 1 January 2021, 88 States declared their participation in the CORSIA scheme. As of 1 January 2022, 19 additional States confirmed their participation in the program, amounting to 107 participating States. As of January 2023, 115 states adhered to the CORSIA scheme.

First phase The first phase, still functioning voluntarily, ranges from 2024 to 2026 and currently records, as of 1st January 2024, 107 participating States.

During these first two voluntary phases, CORSIA applies only to international flights between partecipating States, excluding those from and to non-partecipating States.

Second phase The second phase, starting from 2027, will be the first mandatory phase. Under the mandatory requirement, CORSIA will apply to all international flight from and to all States, with the exception of "small islands, least developed countries, land-locked developed countries and states having less than 0.5% of air traffic" (indicated in yellow in the below Figure 12). However, the excluded state can still operate under CORSIA on a voluntary basis (IATA, 2023b).

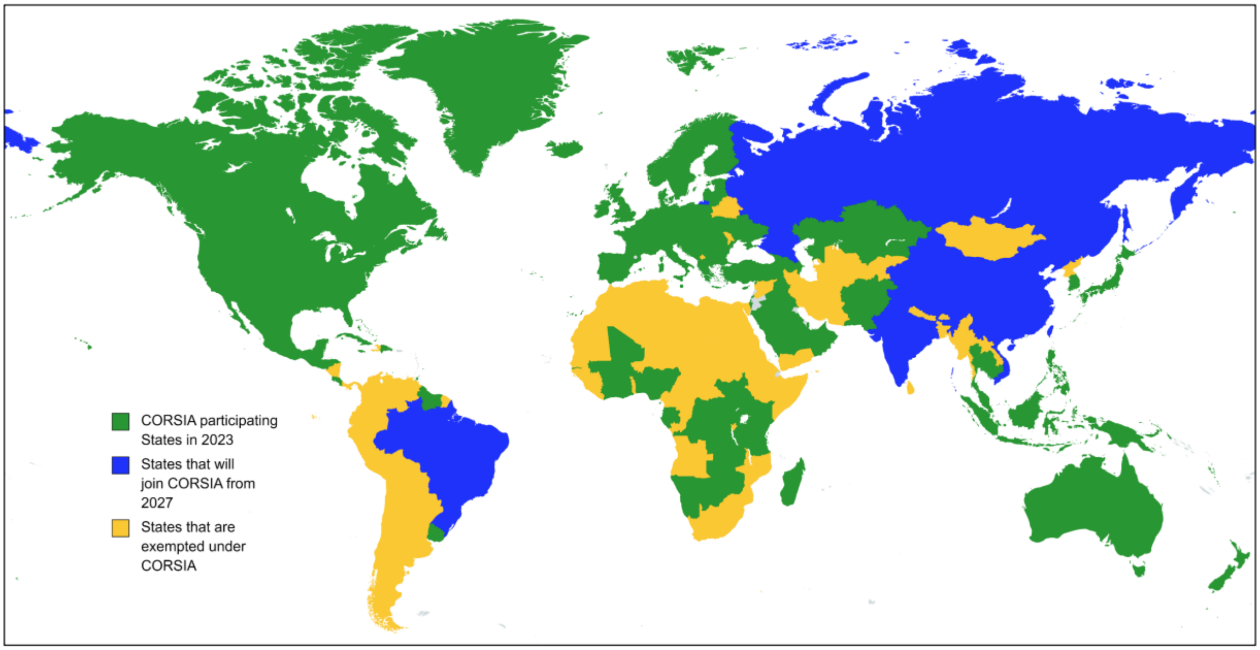

Figure 12: World map showing the States participating voluntarily in the CORSIA scheme as of 2023 (in green); the application will then be extended mandatorily to all States (in blue) from 2027 (second phase), excluding "small islands, least developed countries, land-locked developed countries and states having less than 0.5% of air traffic" (in yellow). (Source: CORSIA Fact sheet, 2023)

According to what is outlined by Assembly Resolution A39-3, the CORSIA program applies to CO_2 emissions stemming from all international flights, ruling out emissions generated from domestic flights, from small operators and small aircraft, and aircraft employed for humanitarian, medical, and rescue purposes.

Reporting requirements Other than establishing a carbon offsetting and stimulation for emission reduction measures mechanism, the CORSIA scheme also outlined, since 1 January 2019, the requirement for all airlines to report annually their emissions stemming from international flights whenever they result in greater than 10,000 tonnes of CO_2. To ensure the effective monitoring of the amount of their CO_2 emissions, airline operators must store the recordings of their fuel use for every single flight by applying one of the five approved fuel use monitoring methods to ensure the accuracy and comparability of reported data. (IATA, 2023b). This reporting tool functions separately from the carbon offsetting mechanism established by the CORSIA scheme. The data retrieved from the reporting aircraft operators will then be elaborated upon to effectively determine the CORSIA's baseline level and the offsetting requirements for aircraft operators.

2.6.2 Sustainable Aviation Fuel (SAF)

Given the forecasted marked surge in commercial air transport demand and the corresponding significant increase in aviation fuel consumption, perpetuating reliance on kerosene - a fossil fuel - to power aircraft engines may not represent the optimal strategy for achieving decarbonization objectives. Consequently, implementing innovative operational and technological enhancements capable of mitigating greenhouse gas emissions from aircraft engines emerges as a fundamental component in effectively attaining ICAO's decarbonization targets. The advancement and increasing deployment of sustainable aviation fuels constitute a pivotal endeavor in propelling the air transport sector toward a decarbonization path, addressing sustainability concerns, and combating climate-related challenges. As previously referenced in *Section 2.5.2* treating the recently introduced technical screening criteria outlined in the EU Taxonomy Regulation for sector-specific economic activities within air transport, alongside the mitigation measures associated with the International Civil Aviation Organization's CORSIA scheme aimed at maintaining CO_2 emissions at baseline levels, the adoption of sustainable aviation fuel (SAF) by aircraft operators assumes paramount importance. Indeed, it is an indispensable requirement for the aviation industry to transition toward a low-carbon economy, constituting one of the strategies with the highest potential for effectiveness. The International Air Transport Association (IATA) expects sustainable aviation fuel (SAF) to account for approximately 65% of emission reductions, enabling the achievement by 2050 of the overarching goal of net zero CO_2 (Figure 13)(IATA, 2023a), resulting in one of the operational improvement measures with the highest potential. Currently, SAF development is still in its early stages, and IATA recalls the need to boost its global development and deployment across industries and countries, emphasizing the essential function of the government in stimulating SAF development by providing harmonized policies and incentives (IATA, 2023a).

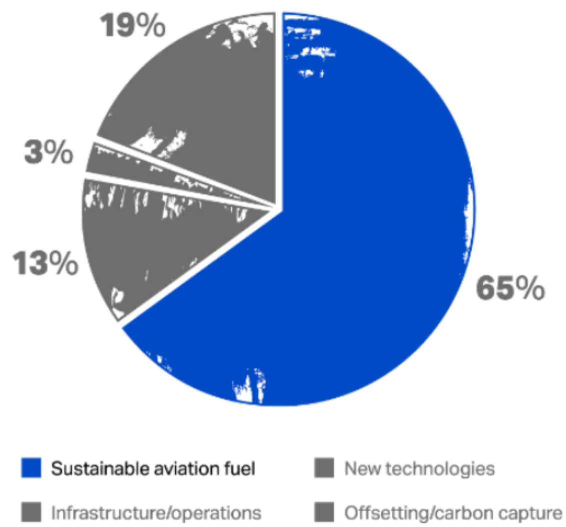

Figure 13: Contribution of sustainable aviation fuel (SAF) to the achievement of the overarching goal of the ICAO's net zero CO_2 by 2050. IATA foresees the increasing deployment of SAF as the sustainability measure with the highest efficiency potential to permit the achievement of the decarbonization goal. (Source: IATA, December 2023, "Net zero 2050: sustainable aviation fuels, Fact sheet")

In particular, sustainable aviation fuels (SAFs)[16] are non-conventional liquid fuels employed in the air transport commercial sector for aircraft engines, obtained from renewable or feedstock waste sources.

The "sustainability" label for this kind of fuel stems from the origin of its feedstock[17] deployed in its elaboration process (feedstock different from traditional crude oil) and from its carbon lifecycle (Figure 14). In particular, SAF can recycle biomass's absorbed carbon dioxide, leading to feedstock growth. Otherwise, it can repurpose waste streams from production processes, processing the sustainable aviation fuel in alternative manners. Consequently, this feature consents to SAF satisfying the sustainability criteria established by Annex 16, Environmental Protection, Volume IV, Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). Hence, SAFs are deemed sustainable thanks to their feedstocks' features, discouraging the most notable environmental issues, such as deforestation, soil productivity loss, or biodiversity loss (IATA, 2020).

[16]This kind of fuel can be denominated in many different ways (e.g., sustainable alternative fuel, sustainable alternative jet fuel, renewable jet fuel or biojet fuel). However, the term sustainable aviation fuel (SAF) results as the main preferred term by IATA to refer to this kind of non-conventional aviation fuel.

[17]SAF's feedstock can range from cooking oil, plant oils, municipal waste, waste gases, and agricultural residues and many others. (IATA, 2020)

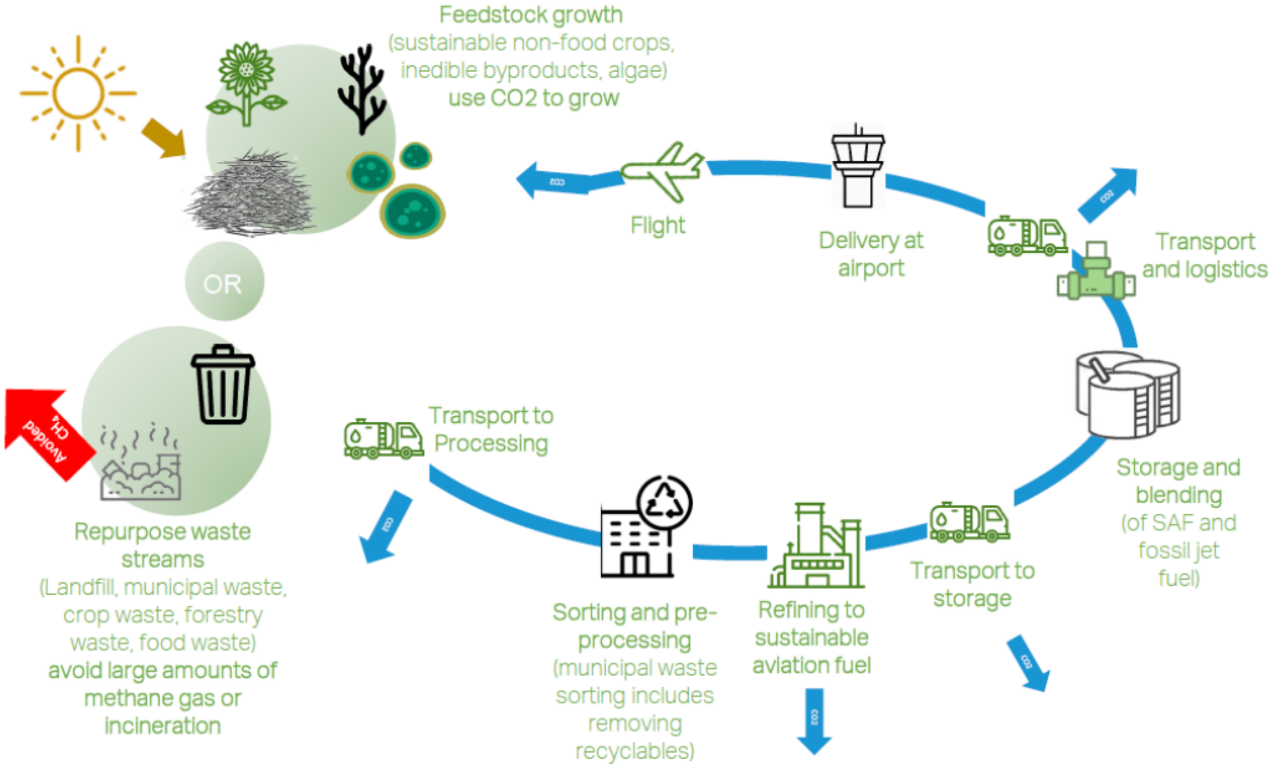

Figure 14: The carbon lifecycle of the sustainable aviation fuel (SAF). (Source: IATA, 2023, What is SAF?)

Environmental point of view From an environmental perspective, alternative sustainably produced fuels, such as sustainable aviation fuels (SAFs), are accountable for lower carbon dioxide emissions, resulting in a comprehensive decrease of CO_2 emissions throughout their carbon lifecycle compared to traditional fossil jet fuels.
Specifically, during the growth process of biomass, plants naturally absorb carbon dioxide, almost offsetting the emissions generated by fossil fuel burning in a combustion engine. This process determines the SAF's carbon cycle, where the carbon dioxide released during its combustion is counterbalanced by what was previously absorbed by plants to grow feedstock, making sustainable aviation fuel (SAF) nearly carbon-neutral throughout its lifespan. However, SAF can be accountable for additional emissions produced during its production processes, such as emissions from the equipment used for crop cultivation, transportation of raw materials, refining processes, and other sources. Considering the above facts, sustainable aviation fuel (SAF)'s increasing deployment in commercial aviation has exhibited noteworthy reductions in overall CO_2 emissions compared to traditional fossil fuels (e.g., kerosene), with the potential of reaching up to 80% of emission reductions in specific contexts (IATA, 2020).
Another feature further defining the environmental sustainability of SAF is its chemical composition, which is which is composed of fewer impurities, such as sulfur, than traditional jet

fuel. The lower concentration of sulfur contributes to additional reductions in sulfur dioxide (SO_2) and particulate matter (PM) emissions (IATA, 2020), which, as mentioned in *Section 2.2*, are a serious concern related to air traffic's impact on climate. Thus, this further emphasizes the crucial role of sustainable aviation fuels in ensuring a transition to cleaner aviation, which provides lower CO_2 and non-CO_2 greenhouse gas emissions.

Adoption of SAF To effectively reach the ambitious goal of net-zero CO_2 in aviation by 2050, airlines must increasingly adopt SAF by blending it with traditional jet fuel or putting it at 100% in their flights. Many airlines already employ SAF in their fleets, disclosing and emphasizing these points in their sustainability strategies. According to IATA predictions, a more significant boost in the adoption of SAF is expected in the 2030s thanks to the future application of global policies and frameworks (e.g., ICAO CAAF/3 elaborated a global framework to stimulate the production of SAF globally for international aviation in November 2023) and to government interventions (e.g., implementing supply-side policies promoting SAF's output), which will encourage both production and deployment of SAF. As of 2023, the SAF production doubled to 600 million liters compared to 2022 recordings, exhibiting 300 million liters (IATA, 2023d), already exhibiting robust progress towards the ambitious decarbonization goal mentioned earlier.

2.6.3 New technologies: Fleet Renewal and Carbon Capture Technologies

In tandem with integrating more sustainable fuels within the aviation sector, developing new aircraft technologies constitutes a pivotal strategy in mitigating emissions and reducing engine noise. Prominent aircraft manufacturers, such as industry leaders Airbus and Boeing, assume a central role in advancing these objectives through their dedicated research efforts aimed at devising innovative approaches to design and produce quieter, less pollutant, and fuel-efficient aircraft. Consequently, numerous airlines are progressively modernizing their fleets as a strategic component of their sustainability agendas, transitioning from non-compliant aircraft to next-generation and compliant models equipped with advanced engines engineered to minimize noise and emissions while optimizing fuel consumption. Furthermore, as mentioned in *Section 2.4.2*, the technical screening criteria required by the Delegated Regulation (EU) 2023/2485 of the EU Taxonomy for aviation-related economic activities state that aviation industry-related economic activities (specified by the relative Delegated Regulation) shall renew their fleets by replacing their non-compliant aircraft with compliant ones (based on the ICAO Aeroplane CO_2 Standard[18]), enabling them to obtain the label of "envi-

[18]Global design certification standard, specified in Annex 16 to the Convention on International Civil Aviation, Environmental Protection, Volume III of March 2017.

ronmentally sustainable economic activity", emphasizing the crucial role of fleet renewal as a fundamental step towards a more sustainable economy in the aviation sector.

ATAG, in its Waypoint 2050 report, developed four possible scenarios concerning the achievement of the aviation sector's 2050 decarbonization goal under different assumptions:

- Scenario 0: baseline / continuation of current trends
- **Scenario 1: pushing technology and operations**
- Scenario 2: aggressive sustainable fuel deployment
- **Scenario 3: aspirational and aggressive technology perspective**

Two of these scenarios heavily shift the focus on aircraft technological improvements. Expressly, Scenario 1 (graph showed in Figure 15) assumes a greater emphasis on technological and operational improvements compared to other strategies, expecting the emergence of unconventional aircraft and a transition of the fleet towards hybrid or electric aircraft from 2035 to 2040, while Scenario 3 (graph showed in Figure 16) emphasizes even more the ambition in implementing technological improvements, expecting the development and deployment of small electric aircraft (up to 100-seat), zero-emissions aircraft (powered by green hydrogen) for the long-haul segment (more than 100 seats) and hybrid-electric configurations for larger sized aircraft (ATAG, 2021).

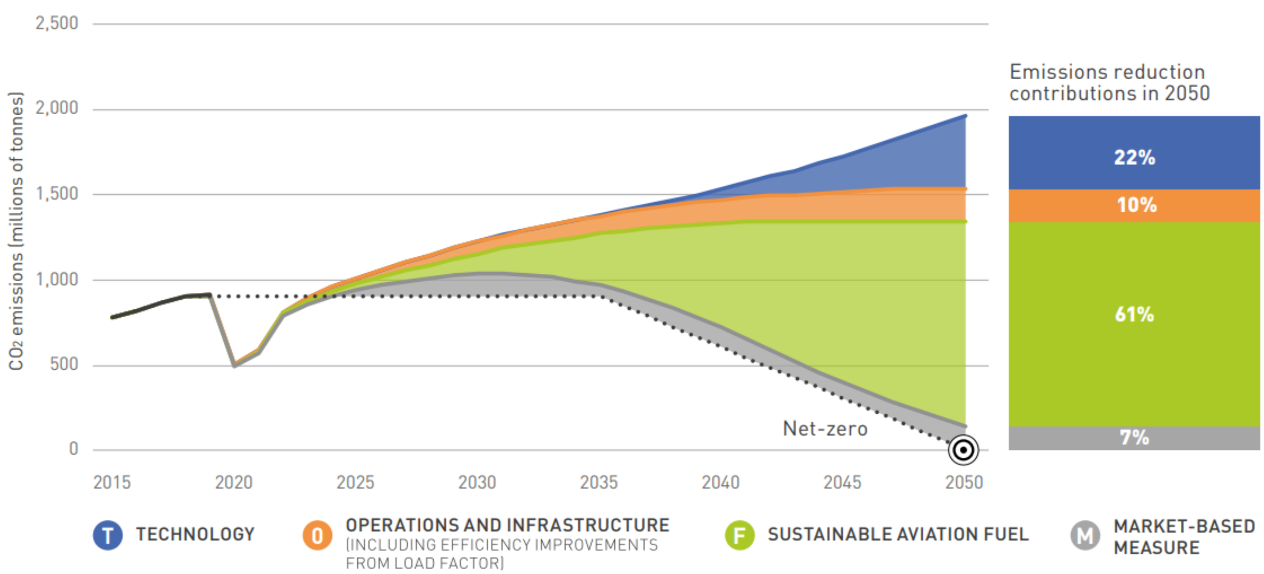

Figure 15: Decarbonization of aviation by 2050 assuming Scenario 1, pushing technological and operational improvements. (Source: ATAG's Waypoint 2050, 2nd edition: September 2021)

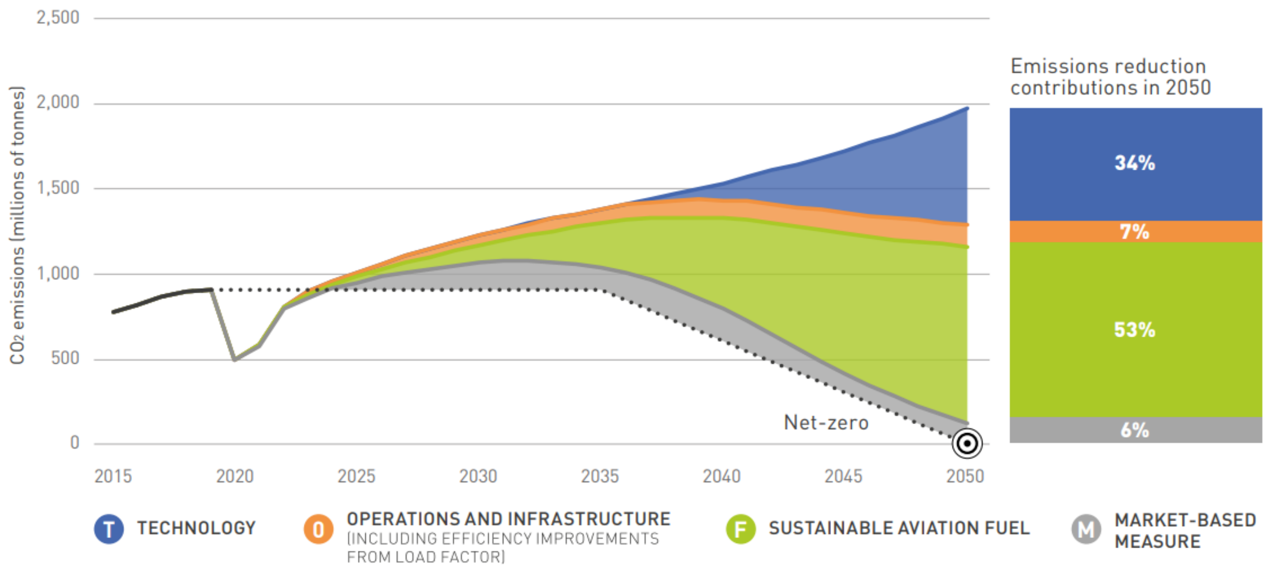

Figure 16: Decarbonization of aviation by 2050 assuming Scenario 3, adopting a more aspirational and aggressive strategy from the technological perspective. (Source: ATAG's Waypoint 2050, 2nd edition: September 2021)

According to the above-represented scenarios, the share of technology improvements, among the other mitigation measures employed in the aviation sector (operations and infrastructure improvements, sustainable aviation fuel (SAF), and market-based measures) to reduce emissions up to the achievement of the net-zero CO_2 goal by 2050, results as the second largest by contribution, preceded by the implementation of sustainable aviation fuel (SAF), which, as mentioned before in *Section 2.5.2* by IATA, represents the emission reduction measure with the highest potential (IATA, 2023d). However, despite the considerable efficiency tied to the introduction of next-generation aircraft as a decarbonization strategy, this measure is constrained by the rate of aircraft entry into the fleet and constraints relative to next-generation aircraft technology innovation, not resulting in an efficient strategy for the near term, but rather for the long-term perspective.

Aircraft manufacturers' most sustainable commercial aircraft In particular, Boeing and Airbus have developed eco-friendly and fuel-efficient aircraft, which both low-cost and legacy airlines have already extensively placed in their fleets.

Among these new fuel-efficient aircraft models, Airbus developed the A320neo, its most successful short-haul aircraft replacing the historical A320 model, which can deliver between 15% and 20% fuel savings compared to its predecessor. In particular, Airbus declared that the A320neo type of aircraft can operate with a 50% blending of sustainable aviation fuel

(SAF), committing to reach a complete amount of SAF in its future A320neo models by 2030 (Airbus, 2022). As of February 2024, over 3,000 A320neo family aircraft have been delivered to airlines by Airbus since 2016 (when A320neo entered into service) (Airbus, 2024), contributing to emission reductions for more than 10 million tons of CO_2. Among the newly designed fuel-efficient aircraft belonging to the Airbus A320 family, we can also notably mention the A321neo, A321neo LR, and the A321neo XLR, a wider-sized aircraft than the A320.In its sustainability strategy, Airbus emphasizes its role in promoting fleet renewal.
Notably, Airbus recalls the effectiveness of its new generation aircraft in reducing air transport's environmental adverse effects, capable of delivering less noise and consuming less fuel than its previous models. In particular, among its quieter and most fuel-efficient new generation aircraft, Airbus mentions:

- **A220**; aircraft model that entered into service in 2016, resulting in a lighter weight than its predecessors' thanks to its optimized aerodynamics, delivering up to 25% of CO_2 emission reduction per seat.

- **A320neo**, aircraft model that entered into service in 2016, equipped with new generation engines capable of extensively reducing emissions compared to its previous versions, delivering up to 20% of CO_2 emission reduction per seat.

- **A330neo**, aircraft model that entered into service in 2018, manufactured with new composite nacelle ensuring enhanced aerodynamics, delivering up to 25% of CO_2 emission reduction per seat.

- **A350**, aircraft model that entered into service in 2015, manufactured with lighter materials, capable of ensuring up to 25% of CO_2 emission reduction per seat.

On the other hand, the Boeing 787 Dreamliner is one the most innovative and efficient commercial aircraft produced by the Boeing aircraft manufacturer. In particular, the 787 Dreamliner is presented by Boeing as a quieter, fuel-efficient aircraft capable of delivering less CO_2 and NO_X emissions, of which Boeing declared the aircraft capability of contributing at least 25% of CO_2 emission reduction, as well as for other non-CO_2 emissions (such as hydrocarbons, smoke, nitric oxide and nitrogen dioxide), resulting below the 2014 ICAO regulatory standards. Concerning noise emissions, Boeing declared that the 787 Dreamliner produces less than 60% noise than its predecessors, making it entirely compliant with the regulatory noise limits in force. The achievement of such extensive noise emission reductions in the 787 Dreamliner comes primarily from aircraft systems improvements (e.g., the Auxiliary Power Unit (APU)) (Boeing, 2016).

Accordingly, several airlines are renewing their fleets by including most of these above-mentioned next-generation aircraft (as will be further exhibited in *Section 3*), disclosing these topics in their sustainability reports, sharing thus their accountability with their stakeholders, and demonstrating how they embrace environmentally responsible behavior by adopting aircraft equipped with quieter and fuel-efficient engines.

Carbon capture technologies Besides innovative technological measures geared towards enhancing aircraft structures and engines, the aviation industry displayed its commitment to implementing carbon capture technologies to mitigate the remaining emissions. In particular, airlines and industry stakeholders have initiated partnerships and collaborations with entities promoting carbon removal projects. In particular, the Intergovernmental Panel on Climate Change (IPCC) argued the crucial role behind developing and adopting such carbon removal technologies to effectively meet the decarbonization target and the Paris Agreement's 1.5°C temperature goal (H. Lee et al., 2023b). Of notable relevance is the Direct Air Carbon Capture and Storage (DACCS) technique, a newly introduced technology that can remove anthropogenic carbon dioxide directly from the air, further enabling the aviation industry to pursue its net-zero carbon emissions target by 2050. In particular, this carbon removal technology functions by sucking air out of the atmosphere, extracting the CO_2 (as well as other greenhouse gases, potentially) present in the latter. Nevertheless, this technology still lies in its early stages, and it is projected to reach the implementation of dozens of DACCS structures by 2030. Additionally, when combined with renewable biomass, CCUS technology stands out as one of the limited carbon abatement methods capable of effectively removing carbon dioxide from the atmosphere. The captured CO_2 can subsequently be implemented to generate Sustainable Aviation Fuel (SAF), leading to ulterior environmental benefits (as mentioned in *Section 2.6.2*) (ATAG, 2023b). However, although CCUS technology development is not a newly introduced technology, it still results in a slow evolution, accounting for an annual investment share of less than 0.5% of all global investments in clean energy and efficiency technologies. Currently, 21 CCUS structures have been implemented worldwide, capable of capturing as much as 40 $MtCO_2$ per year (IEA, 2023c).

2.6.4 Voluntary Carbon Offsets (VCO)

Despite the technological advancements implemented by aircraft manufacturers geared towards producing more efficient and fuel-efficient aircraft, the scope of single-aircraft technological innovations encounters inherent physical constraints in effectively reducing greenhouse gas emissions. Therefore, a comprehensive amalgamation of diverse measures is imperative to effectively pursue a successful pathway toward decarbonization. These measures encompass market-based measures (e.g., EU ETS and CORSIA scheme), the deployment of sustainable aviation fuel (SAF), technological and operational enhancements, and voluntary carbon offsetting programs. This multifaceted approach is posited as the most efficient strategy to realize the ambitious goal of achieving net-zero CO_2 emissions within the aviation sector by 2050 (Becken & Mackey, 2017).

Voluntary carbon offsetting (VCO) programs are tools that airlines employ to raise awareness among passengers about the extent of CO_2 emissions released during flights and to encourage them to compensate for the proportion of their flight's carbon emissions by paying or investing extra money in carbon reduction projects during the ticket purchasing phase. The funds raised through VCO will not prevent the aircraft itself from emitting fewer emissions; instead, these funds will be invested in decarbonization projects designed to prevent or capture CO_2 emissions from other sectors.

Being a voluntary program, passengers can choose whether or not to pay extra for offsetting carbon emissions based primarily on their sociodemographic attributes (i.e., age, gender, level of education, income), sense of responsibility, environmental beliefs and awareness, trip frequency, and the relative credibility they put on the airline's sustainable behavior, as demonstrated by several studies and research outlined in *Section 2.1.*

Currently, according to the IATA website, more than 50 airlines already introduced voluntary carbon offsetting schemes in their sustainability strategies by directly implementing the mechanism in their website during the sale of ticket stage or by instructing third-party offsetting providers.

However, according to some studies and available data, voluntary carbon offsetting exhibited its scarce capability to significantly contribute to reducing air travel demand and consequently lessening CO_2 air traffic-related emissions. Being voluntary, the effectiveness of these schemes relies on their widespread adoption and acceptance by passengers. However, a large part of airlines demonstrated their reluctance to disclose the rate of passengers' contribution to voluntary carbon offsetting schemes, confirming the inefficiency of this strategy. A notable example of the inefficiency of voluntary carbon offsetting schemes has been provided by British Airlines, which declared that the amount of voluntary offset by passengers reached only 3,000 tonnes in 2007, versus a total of 27 million tonnes since adopting the voluntary offsetting scheme, amounting to a 0.01% of total emissions. However, two years after these first scarce results, the percentage of emission voluntarily offset by passengers increased to 0.3%, displaying a tiny improvement (Davies, 2007).

In light of what has been said before, considering and comparing with other mitigation strategies and mandatory carbon offsetting schemes, the efficiency and related capability to reduce emissions provided by voluntary carbon offsetting schemes is quite restricted, affirming its minimal efficiency as a mitigation strategy in the airline industry. However, airlines might choose to implement voluntary carbon offsetting measures in their strategies to enhance their green reputation, appear as a more environmentally sustainable business, and perhaps incur the risk of "greenwashing" their services (Knorr & Eisenkopf, 2020).

2.6.5 Enhanced Operational Efficiency and Infrastructure Improvements

In the effective pursuit of the ICAO's decarbonization goal, the aviation industry shall earmark delivering the maximum lessening in emissions at source via the employment of sustainable aviation fuels (SAF), innovative propulsion technologies, and other efficiency refinements related to air traffic navigation (IATA, 2023c). Among those, operational efficiency improvements consist of aircraft operations adopted by airlines and aircraft operators and infrastructure improvements (air traffic management) aimed at enriching operational efficiency and lessening fuel consumption.

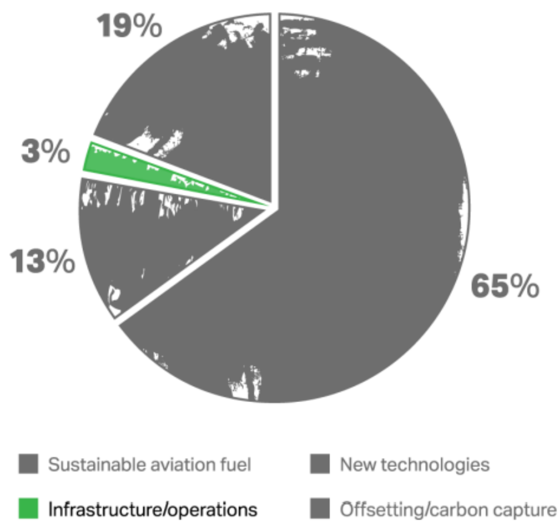

Figure 17: Contribution of operational and infrastructure refinements to the achievement of the overarching goal of the ICAO's net zero CO_2 by 2050. IATA foresees operational and infrastructure refinements would result in the least contributing sustainability measure to achieving the decarbonization goal. (Source: IATA, December 2023, "Net zero 2050: operational and infrastructure improvements - Fact sheet")

In particular, efficiency improvements related to aircraft operations consist of measures geared towards reducing aircraft weight and enhancing the aerodynamics of aircraft in service; variously, infrastructure improvements consist of measures aimed at implementing structural changes in air traffic management (ATM) operations and energy savings at the airport area (e.g., limitations on the use of auxiliary power units, single-engine taxi, decreased taxi times)

(IATA, 2023c).
Various strategies are employed within the aviation industry to enrich fuel efficiency and reduce emissions. Among these strategies vaulted at improving operational efficiency, we can notably mention the implementation of retrofitting winglets for aerodynamic improvements, capable of delivering over 4% fuel savings, noise reduction, and decreased NOx emissions, with more than 9,000 aircraft retrofitted since 2000, the aviation industry has collectively saved over 100 million tonnes of CO_2; the adoption of lightweight cabin equipment (e.g., electronic flight bags), seating, and cargo containers; implementation of electric or assisted taxiing techniques, exemplified by reduced engine taxiing practices leading to substantial fuel savings; and the use of exterior paint with thinner, more aerodynamically efficient, and better-maintained paint schemes contributing to enhanced aerodynamic efficiency (IATA, 2023c).
In the realm of air traffic management (ATM), three cornerstone programs have been implemented to enhance its efficiency, enforce emissions reduction measures, and optimize airport operations. These core initiatives, identified as the **Single European Sky**, **NextGen**, and the **ICAO Aviation System Block Upgrades**, are pivotal endeavors within the ATM domain.

Single European Sky (SES) The introduction of the Single European Sky (SES) initiative, dating back to 1999, marked a pivotal step geared towards enhancing the efficiency and enabling modernization of air traffic management (ATM) and air navigation services (ANS) by fostering a more cohesive integration of European airspace (EP, 2023). The forecasted benefits outlined by the SES initiative hold considerable promise: upon its estimated finalization around 2030-2035, it has the potential to triplicate airspace capacity compared to the baseline in 2004 (EP, 2023). Moreover, the initiative envisages halving ATM costs, as well as implementing a tenfold enhancement in safety standards and a reducing by 10% the environmental impacts for which the aviation industry is accountable (EP, 2023). However, despite its initial promises expected to be attained by 2020, the progress towards SES could have been faster, limped by institutional resistance and a need for more political leadership. Thereby, in September 2020, the European Commission intervened to redirect to the finalization of SES's objectives, recalling a new accelerated action plan, the SES2++ proposal. In particular, this new SES proposal presents an exceptional opportunity to foster a broad modernization within Europe's airspace for the forthcoming three decades. However, achieving a successful implementation of the SES initiative hinges upon a strong dedication from states, businesses, aviation industry stakeholders, and regulators to ensure its realization. Specifically, IATA, as a whole, expressed its active commitment to materializing the SES objectives (IATA, 2021).

NextGen The Next Generation Air Transportation System (NextGen) is a significant initiative introduced by the Federal Aviation Administration (FAA) in the early 2000s[19] to modernize the U.S. National Airspace System (NAS) comprehensively. This initiative, already operative and planned to be finalized by 2030, encompasses implementing refinements to airport infrastructure, adopting new air traffic management technologies and procedures, and introducing better and enhanced safety and security measures. In addition, NextGen strives to contribute to aviation's environmental impact mitigation by supporting programs promoting sustainable aviation fuel adoption and fostering the development of fuel-efficient and less-pollutant aircraft and engines (FAA, 2023).

ICAO Aviation System Block Upgrades (ASBU) The Aviation System Block Upgrades (ASBU) methodology developed by ICAO represents a comprehensive and adaptable global strategy that is vaulted at enabling Member States to improve their air navigation capabilities and tailor them to their specific operational requirements (ICAO, 2024). This structured framework, first introduced by ICAO during the 12th Air Navigation Conference in November 2012, aims to promote global harmonization, bolster capacity, and enhance environmental efficiency in reaction to the evolving global demand for modernized air traffic (ICAO, 2024). Member States collaborate with the International Civil Aviation Organization (ICAO), their Air Navigation Service Providers, and aviation industry stakeholders within the ASBUs framework to develop and implement specific and individually designed air navigation enhancements in a coordinated manner in pursuit of specific operational requirements (ICAO, 2024). By aligning with these particular operational requirements, Member states can optimize their airspace capacity, safety, and efficiency on a harmonized and expedited basis (ICAO, 2024). In particular, the ASBU methodology concentrates its enhancement efforts on four specific areas:

- airport operations;
- global interoperable systems and data;
- optimum capacity and flexible flights;
- efficient flight paths (ICAO, 2016).

[19] December 15, 2004.

2.6.6 Sustainable Cabin Practices

Other than employing measures geared towards enhancing operational efficiency, fuel consumption, and next-generation technologies to mitigate emissions, among other initiatives, airlines are also focusing on adopting sustainable cabin practices to successfully accomplish the pursuit of a decarbonization path. Starting from the common concern of people regarding the impact of single-use plastics on the marine environment, governments and all economic sectors concentrate on sustainable initiatives, particularly addressing concerns over single-use plastics and waste management. In response, airlines are also taking their own part by committing to aligning their efforts with these sustainability initiatives despite lacking a specific regulatory framework for cabin waste management and circular economy (Esposito, Tse, & Soufani, 2018)(Ghisellini, Cialani, & Ulgiati, 2016). Nevertheless, to address potential challenges associated with cabin waste, the International Air Transport Association (IATA) has declared its commitment to supporting simplified and harmonized cabin waste regulations by implementing technical solutions aimed at reducing industry costs and promoting the realization of a circular economy.

Cabin waste management must be strongly considered when dealing with sustainability, as its increasing costs could deplete airlines' valuable resources and consequently hinder the airlines' corporate reputation and credibility in terms of sustainability initiatives. IATA's data revealed that airlines generated approximately 5.7 million tonnes of cabin waste in 2017, amounting to US$ 927 million borne by the industry (IATA, 2019). Without implementing any action and considering the ever-growing passenger growth rate[20], cabin waste quantities could significantly increase accordingly in the next decade, driving even higher costs for the airline industry. From literature, some studies argue that the most significant part of global airline industry waste comes from cabins (Kleymann & Seristö, 2017), which results generated by passengers for approximately 70% (Abdullah, Chew, & Hamid, 2016) (Salesa, León, & Moneva, 2023).

To support the airline industry in overcoming the challenges concerning circular economy by implementing appropriate cabin waste reuse and recycling programs, IATA, in collaboration with WRAP[21], elaborated the Cabin Waste Handbook (IATA, 2019), outlining how to execute cabin waste management and other related practices effectively.

Additionally, IATA, supported by Travel Without Plastic and WRAP, has recently published the "Reassessing Single Use Plastic Products in the Airline Sector" report. This report intends to assist airlines, regulatory bodies, and suppliers within the airline industry

[20] Passenger growth rate resulted of 7.6% per year as of 2017. (IATA, 2019)

[21] WRAP is not-for-profit, working with governments, businesses and citizens to promote the creation of a world in which resources are utilized in a sustainable manner (IATA, 2019).

in handling and reducing the environmental consequences associated with single-use plastic products (SUPP). Therefore, the report chiefly focuses on easing the development, adaptation, and implementation of solutions tailored to the aircraft's distinctive environment and structure, thus efficiently mitigating the environmental impact of single-use plastics (IATA, 2024b).

3 Airlines and Environmental Sustainability

Airlines, the primary actors in undertaking the business of providing air transportation services connecting people worldwide, are specifically accountable for greenhouse gas emissions and their related environmental impacts deriving from air traffic. Therefore, considering the ever-increasing awareness of the environmental repercussions related to climate change and the uptaking of the sustainability concept in global debates, all businesses and economic activities, comprising airlines, are progressively embracing and implementing a well-suited combination of sustainable practices and strategies to successfully align with decarbonization goals, such as the one set by ICAO, and the Paris Agreement one, while reducing their emission intensity (which in aviation is measured by CO_2 per passenger (pax)/km), addressing stakeholder sustainability expectations.

This section analyzes the sustainability profiles within the environmental pillar of diverse airlines from two different business models: low-cost carriers and legacy airlines. Within each classification, two distinct airlines will be scrutinized regarding mitigation strategies, outlining if and how they incorporate the sustainability accounting standards prescribed by the Sustainability Accounting Standards Board (SASB) designed specifically for airlines, which have been mentioned and described in *Section 2.4.1*.

3.1 Low-cost Carriers: easyJet plc and Ryanair Holdings plc

3.1.1 easyJet plc

Airline description easyJet plc, a prominent player in the airline industry, is a British airline established in 1995 and headquartered at London Luton Airport. The company, recognized for its innovative business model and widespread operational footprint in the European landscape, has become one of the largest airlines in the world, operating 1,024 routes across 36 countries and 155 airports within Europe (easyJet, 2024). The airline started as a pioneer of the low-cost carrier model, further affirming its position as a provider of point-to-point air travel, offering affordable and accessible services for a wide range of clients thanks to its cost advantage strategy. In pursuing its sustainability strategy, easyJet plc possesses a modern and fuel-efficient aircraft fleet, emphasizing operational efficiency while minimizing its environmental impact.

To analyze how easyJet plc has addressed sustainability concerns regarding the environmental dimension, we will scrutinize its Annual Report and Account 2023 (easyJet, 2023) relative to the period from 30 September 2022 to 30 September 2023.

easyJet plc and Sustainability By analyzing easyJet plc's sustainability approach concerning FY2023, the low-cost carrier kept displaying its commitment to pursuing the ICAO's decarbonization goal by 2050 with its "Net zero pathway" strategy, aimed at addressing both CO_2 and non-CO_2 effects. It claimed its aspiration to deliver carbon emission intensity reductions of 78% by 2050 and of 35% by 2035 (against the FY2019 baseline) (easyJet, 2023), addressing residual emissions through carbon removal technologies. In particular, the company disclosed its emission intensity indicator resultant for FY2023 amounting to 67.23g CO_2 per passenger (pax)/km, resulting in 4.66% less than the one recorded in FY2022 (70.36g CO_2 per passenger (pax)/km). easyJet also hit a 5% emission reduction compared to FY2019, exhibiting more than 500,000 tonnes of CO_2e savings, thanks to its combination of mitigation strategies, comprising fleet renewal, operational refinements, and adoption of sustainable aviation fuel (SAF) (easyJet, 2023) .

Fleet renewal Fleet renewal is one of easyJet plc's leading strategies for reducing emissions by replacing older aircraft models with brand-new fuel-efficient and quieter aircraft. In particular, easyJet plc proceeded to renew its fleet in recent years, replacing the A319 and A320s with the A320neo aircraft family (comprising A320neo and A321neo aircraft), a well-known family of aircraft produced by the Airbus aircraft manufacturer company renowned for their fuel-efficient and quieter engines. According to easyJet plc, a fleet renewal strategy can deliver short- and medium-term enhancements in the company's emissions intensity (easyJet, 2023).

Aircraft in fleet at 30 September 2023

	Total	*Owned*	*Leased*
A319	**95**	29	66
A320	**172**	103	69
A320neo	**54**	47	7
A321neo	**15**	4	11
Total	**336**	**183**	**153**

Aircraft in fleet at 30 September 2022

	Total	*Owned*	*Leased*
A319	**94**	35	59
A320	**167**	105	62
A320neo	**44**	37	7
A321neo	**15**	4	11
Total	**320**	**181**	**139**

Table 3: easyJet plc's aircraft in fleet: comparison between FY2023 and FY2022. (Source: easyJet plc's Annual Report and Accounts, FY2023 and FY2022)

Table 3 displays easyJet plc's fleet during FY2022 (right-hand side) compared to FY2023 (left-hand side). By observing the two represented tables, it can be inferred that the British low-cost airline proceeded to increase the size of its fleet in FY2023 compared to FY2022 by directly buying ten brand-new A320neo fuel-efficient aircraft. The company also declared its ambition to proceed with the delivery of an additional 158 brand-new A320neo and A321neo[22] aircraft by FY2029 (easyJet, 2023) . Specifically, the new aircraft belonging to the A320neo family result capable of delivering 50% noise reduction and almost 15% of additional fuel efficiency compared to its antecedent models (i.e., A319 and A320 current-engine option). In addition to the entrance of new A320neo aircraft into the fleet, the low-cost airline claimed that the A320 previous models present in the fleet have been delivered with 'Sharklet' wingtips since 2013, which consist of a technical feature capable of reducing up to 3% of aerodynamic drag and fuel burn per hour flown (easyJet, 2023).

Noise reduction easyJet plc is pursuing noise impact reduction by employing new, quieter, and fuel-efficient aircraft from the A320neo family in its fleet and instructing flight crew to use specialized techniques designed to minimize noise emissions, resulting in compliance with noise abatement procedures (easyJet, 2023). In particular, the A320neo and A321neo aircraft results conform to ICAO Chapter 14 regulations, thanks to the aircraft's CFM LEAP-1A engines (easyJet, 2023).

Operational and efficiency improvements The low-cost carrier also states that implementing efficiency improvements to reduce fuel burn and related carbon emissions from the flight profile perspective is one of the strategies to reduce its carbon footprint (easyJet, 2023).
In particular, this set of refinements consists of measures aimed at covering all the flight phases, from departure to arrival, to improve flight efficiency. easyJet plc does that also by establishing partnerships with aircraft manufacturers and other entities, such as Airbus, Collins Aerospace, NATS, and Eurocontrol (easyJet, 2023). In particular, the company is embracing advanced technological tools, including integrating artificial intelligence (AI) and big data analytics, such as *"SkyBreathe"*, a fuel management tool. *"SkyBreathe"* is an innovative solution capable of gathering and analyzing all the data regarding easyJet plc's fleet, combining it with additional external information, such as meteorological conditions and air traffic control (ATC) data, ending up with an identification of optimal fuel-saving opportunities, enabling the airline to optimize its ground and on-flight operational procedures, enhancing in a comprehensive way efficiency and resource-use (easyJet, 2023).
The company also invested substantial funds in implementing two innovative software upgrades in its aircraft, designed to minimize fuel burning and emissions during the descent

[22] "neo" stands for "new engine option."

phase. These software upgrades are denominated as *Descent Profile Optimisation (DPO)* and *Continuous Descent Approach (CDA)*, designed to compute and operate a descent trajectory burning minimum fuel and minimizing emissions and noise (easyJet, 2023). Regarding these innovative software upgrades, easyJet plc claimed that it has installed the new upgrades on 332 aircraft in its fleet, holding the title of the airline with the world's largest DPO/CDA-enabled fleet (easyJet, 2023).

Airspace modernization The modernization of airspace is regarded by easyJet as an effective mitigation strategy, capable of enabling an efficient optimization of the air traffic management system while safeguarding the environment, addressing both carbon emissions and non-CO_2 effects in the short and medium periods.
In particular, the airline established a close partnership with Inmarsat, the European Space Agency, and Airbus, which are, in collaboration, leading the pioneering air traffic management program called *"Iris"*, an initiative enabling new air traffic management functionalities for which easyJet plc is evaluating and going to test its efficiency with trials foreseen to begin in the first half of FY24 (easyJet, 2023). The airline company also established partneships with several stakeholders and entities within Europe and UK to engange in projects aimed at modernizing airspace fostering ATM efficiency, such as:

- Single European Sky (SES) project (Europe, described in *Section 2.6.5*)
- A4E's Airspace Working Group membership (Brussels)
- HERON project (three-year program led by Airbus)

New technology Hydrogen technology conveys a vital cornerstone for a decarbonized future in short-haul flights, and easyJet plc acknowledges the urgency of further investing in advancements and research on such technology. In particular, easyJet has stipulated an innovative partnership with the engine manufacturer Rolls-Royce geared towards designing hydrogen combustion aircraft engines. In particular, in 2022, the two companies executed the first-of-its-kind aero engine powered by green hydrogen, marking a fundamental step in technological innovation in aviation (easyJet, 2023).

Internal carbon price easyJet plc decided to implement an internal carbon price, based on ETS costs, to monitor and evaluate compliance with current and future obligation costs deriving from long-term emissions impacts (easyJet, 2023). easyJet plc implemented the internal carbon price in its financial frameworks to evaluate the feasibility and profitability of its projects, encompassing the five-year financial plan, the 10-year funding model, and the airline's budgetary allocation (easyJet, 2023).

Voluntary Carbon Offsetting (VCO) In September 2022, easyJet plc disclosed a change in its sustainability strategy, shifting from reliance on voluntary carbon offsetting schemes towards investments supporting next-generation technologies (e.g., Rolls-Royce's hydrogen engine partnership and Airbus and 1PointFive's scaling Direct Air Carbon Capture and Storage (DACCS)), an essential ingredient for realizing the airline's ambitious "Net zero pathway" trajectory. Therefore, commencing January 1, 2023, the airline stopped offsetting carbon emissions for new bookings while maintaining its pre-existing carbon offset obligations to customers who made reservations on or before December 31, 2022 (easyJet, 2023).
As mentioned in *Section 2.6.4*, voluntary carbon offsetting initiatives demonstrated their inefficiency in reducing carbon footprint compared to other strategies, explaining why some airlines, such as easyJet plc, desist from retaining VCOs as part of their sustainability strategy.

Sustainable Aviation Fuel (SAF) easyJet plc believes that in anticipation and pending of technological innovations promoting zero carbon emission aircraft, the reliance on the employment of sustainable aviation fuel (SAF) turns out to be an effective tool in accelerating the aviation sector's decarbonization. These conclusions align with what has been recalled by ICAO, claiming that SAF's employment results as the strategy with the highest potential in contributing to the net zero goal by 2050 (*Section 2.6.2*). However, despite the several challenges posed by the limited provision and expensiveness of SAF within the aviation industry, easyJet plc currently employs SAF in France, according to the French national mandate for SAF usage on domestic routes (easyJet, 2023). Additionally, easyJet plc is cooperating with its primary fuel suppliers establishing long-term by establishing agreements to adopt SAF in its flights in the coming years, ensuring compliance with EU member countries and UK mandates on SAF utilization (easyJet, 2023).

Carbon Removals easyJet plc regards implementing carbon removal technology, such as Direct Air Carbon Capture and Storage (DACCS), as a crucial strategy for effectively pursuing its net zero trajectory, geared towards primarily addressing residual carbon emissions stemming from its aircraft. As recalled in *Section 2.6.3*, DACCS's functionality derives from its capability of effectively capturing CO_2 from the atmosphere, storing it, and its potential to be implemented for producing sustainable aviation fuel.

Concerning easyJet's strategy, in FY2023, the airline company established an agreement with the aircraft manufacturer Airbus, where the latter, from 2026 to 2029, will provide easyJet with the carbon removal credits deriving from its DACCS plant established in Texas (easyJet, 2023). Afterward, the company intends to unlock the eligibility of these credits for the CORSIA and the ETS scheme for aviation (easyJet, 2023).

Sustainable cabin practices: waste management During 2023, easyJet plc implemented specific protocols for waste segregation onboard, which enhanced efficacy and legal adherence to recycling practices according to the International Catering Waste (ICW) legislation (easyJet, 2023). Thanks to continuous back-and-forths with airport partners, the airline effectively addresses waste management concerns, augmenting the recycling rates of its base airports to 50% compared to the ones recorded in FY2022, amounting to 31%. Despite the considerable increase in total onboard waste related to the rising number of passengers (increasing from 0.07 kg/pax[23] in FY2022 to 0.09 kg/pax in FY2023) (easyJet, 2023), easyJet plc still maintains its commitment to pursue enhancements in its food and beverage services onboard, focusing on reducing the utilization of single-use plastics and extra packaging materials (easyJet, 2023). Again, in FY2023, the low-cost carrier tested an initiative prescribing the employment of reusable cups and utensils for crew meals, which is expected to be fully implemented during the first quarter of FY2024 (easyJet, 2023).

Sustainability Standards and Frameworks As part of its sustainability standards and frameworks easyJet plc conceived its Sustainability Report by adopting the following standards:

- Sustainability Accouting Standards Board (SASB) industry-specific standards specifically designed for airlines;
- Task Force on Climate-related Financial Disclosures (TCFD) for reporting on climate risks and opportunities.

Further, easyJet plc declared that it is currently becoming more familiar with the upcoming International Sustainability Standards Board (ISSB) reporting standards and the European Corporate Sustainability Reporting Directive (CSRD) provisions.

As tied to the previous *Section 2.4.1* of this work, we will analyze the SASB standards provided data related to the environmental sustainability pillar of the low-cost airline easyJet plc for FY2023 compared to the ones of FY2022.

[23] Waste per passenger (in kg).

Topic	*Accounting metric*	*Category*	*Unit of measure*	*Code*	**FY2023**	**FY2022**
Greenhouse gas emissions	Gross global Scope 1 emissions	Quantitative	Metric tonnes (t) CO_2e	TR-AL-110a.1	7,517,925	6,421,434
	Discussion of long-term and short-term strategy or plan to manage Scope 1 emissions, emissions reduction targets, and an analysis of performance against those targets		n/a	TR-AL-110a.3	Discussed below	-
	(1) Total fuel consumed	Quantitative	Gigajoules (GJ)	TR-AL-110a.3	103,880,085	86,363,466
	(2) Percentage alternative	Quantitative	Percentage (%)		0.020%	Not disclosed
	(3) Percentage sustainable	Quantitative	Percentage (%)	TR-AL-310a.1	0.020%	Not disclosed
Labour practices	Percentage of active workforce covered under collective bargaining agreements	Quantitative	Percentage (%)	TR-AL-310a.1	85%	86%
	(1) Number of work stoppages and (2) Total days idle	Quantitative	Number, days	TR-AL-310a.2	Not disclosed	Not disclosed
Competitive behaviour	Total amount of monetary losses as a result of legal proceedings associated with anticompetitive behaviour regulations	Discussion and analysis	n/a	TR-AL-540a.1	Zero	Zero
Accident and safety management	Description of implementation and outcomes of a safety management system	Discussion and analysis	n/a	TR-AL-540a.1	-	-
	Number of aviation accidents			TR-AL-540a.2	Zero	Zero
	Number of governmental enforcement actions of aviation safety regulations			TR-AL-540a.3	Zero	Zero

Table 4: SASB Sustainability Disclosure Topics & Accounting Metrics for Airlines relative to the easyJet plc Annual Report and Accounts for FY2023 compared to FY2022. (Source: easyJet plc's Annual Report and Accounts, FY2023 and FY2022)

By observing the first set of rows related to the "Greenhouse gas emissions" topic in Table 4, the SASB standards first require the company to disclose the **gross global Scope 1 emissions**, consisting of all the greenhouse gas emissions stemming directly from the sources managed and owned by the airline while excluding the carbon removals, generated during its reporting period, expressed in metric tonnes CO_2e. Scope 1 emissions are reported according to the GHG Protocol global framework, a standardized tool enabling firms to measure their greenhouse gas emissions effectively.

The accounting metric relative to the **gross global Scope 1 emissions** states that easyJet plc emitted 7,517,925 $MtCO_2$ for FY2023 and 6,421,434 $MtCO_2$ in FY2022. We can notice that, despite the plenty of sustainability efforts put in place by easyJet, the low-cost airline experienced a 17.08% increase in gross Scope 1 emissions in the last year, which might be due to the steady rate at which demand for air travel is increasing. The data listed in the *"Activity metric"* column represented in Table 5 might exemplify the registered increase in emissions. In particular, the activity metrics "Available Seat Kilometres (ASK)" and "Revenue Passenger Kilometres (RPK)" all display a substantial surge in FY2023 compared to FY2022.

- **Available Seat Kilometres (ASK)** metric represents the maximum potential cumulative kilometers traveled by passengers, comprising both aircraft's occupied and unoccupied seats; from FY2022 to FY2023, easyJet experienced a 16,49% increase in ASK.

- **Revenue Passenger Kilometers (RPK)** metric represents the cumulative total kilometers traveled by passengers who have effectively paid the airline to benefit from the air travel transportation service; from FY2022 to FY2023, easyJet experienced a 21.34% increase in RPK.

The qualitative accounting metric *"Discussion of long-term and short-term strategy or plan to manage Scope 1 emissions, emission reduction targets, and an analysis of performance against those targets"* requires the airline to draft an explanatory overview of all the sustainability strategies undertaken to mitigate its Scope 1 emissions and the relative set up of its short- and long-term targets. For FY2023, the easyJet sustainability approaches relative to Scope 1 emission mitigation are discussed in the previous paragraph *"easyJet plc and Sustainability"*.

The last three rows related to the "greenhouse gas emissions" topic regard fuel, in particular (1) requires the airline to indicate the total amount of fuel utilized, and (2) and (3) the percentage of alternative fuel and sustainable aviation fuel (SAF) employed.

- easyJet declared that it had consumed a total of 103,880,085 Gigajoules of fuel in FY2023, an increase equal to 20.28% of fuel consumed compared to FY2022. This increase was mainly due to the increase in air travel demand exemplified before.

- Concerning the accounting metrics (1) and (2), easyJet plc did not disclose any data for FY2022, while for FY2023, it declared that it had employed 0.020% of both alternative and sustainable aviation fuel (SAF).

Activity metric	*Category*	*Unit of measure*	*Code*	**FY2023**	**FY2022**
Available Seat Kilometers (ASK)	Quantitative	ASK (Millions)	TR-AL-000.A	113,334	97,287
Passenger load factor	Quantitative	Rate	TR-AL-000.B	89.3%	85.5%
Revenue Passenger Kilometers (RPK)	Quantitative	RPK (Millions)	TR-AL-000.C	102,984	84,874
Revenue Tonne Kilometers (RTK)	Quantitative	RTK	TR-AL-000.D	882	909
Number of departures	Quantitative	Number	TR-AL-000.E		
Average age of fleet	Quantitative	Years	TR-AL-000.F	9.9 years	9.33 years

Table 5: SASB Activity Metrics for Airlines relative to the easyJet plc Annual Report and Accounts for FY2023 compared to FY2022. (Source: easyJet plc's Annual Report and Accounts, FY2023 and FY2022)

3.1.2 Ryanair Holdings plc

Airline description Ryanair Holdings plc, or Ryanair, is a leading Irish low-cost airline headquartered in Dublin, Ireland. Since its establishment in 1984, the airline has grown considerably, becoming one of the largest and most successful low-cost carriers worldwide. Originally established as "Ryanair DAC" in 1984, the airline then expanded as "Ryanair Holdings" in 1996, incorporating also the subsidiaries Ryanair DAC, Malta Air (from 2019), Buzz, Lauda Europe and Ryanair UK.
Its operations primarily cover the European continent, serving 250 destinations in 37 European countries and extra-European countries, such as North Africa, where the airline strives to create connections to major cities and popular tourist destinations (Ryanair, 2024).
Ryanair is recalled for its no-frills approach, offering its clients flight options with no extra unnecessary services, granting affordable air travel, and emphasizing efficiency and cost-saving. To minimize operational expenses, the low-cost airline adopts a point-to-point business model, where flights operate between secondary airports, often outside major cities. Although Ryanair has frequently been criticized for its strict policies and customer service standards, the airline keeps attracting millions of passengers annually, operating over 2,600 daily flights, affirming its leading position in the European low-cost airline industry.

To further analyze how Ryanair Holdings plc has managed sustainability concerns regarding the environmental dimension we will scrutinize the Sustainability Report 2023 (Ryanair, 2023), covering the period from 1 April 2022 to 31 March 2023.

Ryanair Holdings plc and Sustainability Given its dominant position in the European airline industry, Ryanair's role in determining the sustainable future of aviation is climactic. In particular, the Irish low-cost airline declared its dedication to achieving the Paris Agreement targets and the ICAO's net zero goal by 2050 through establishing an all-around Climate Transition Plan ("the Plan"), announcing, in 2022, its ambition to reach the net zero CO_2 emission long-term goal by 2050 (Ryanair, 2023). Ryanair Group's ambitious plan to transition to net zero encompasses a series of sustainability approaches, ranging from fleet renewal and implementation of new technologies to increasing employment of sustainable aviation fuel.

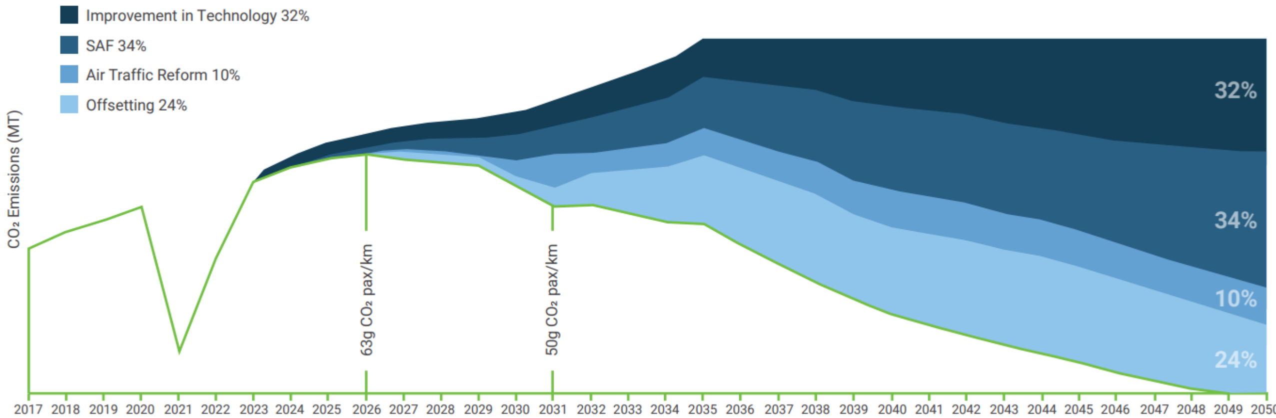

Figure 18: Ryanair Path to Net Zero. (Source: Ryanair Group Sustainability Report, 2023)

By observing Figure 18, we can notice that Ryanair claims that a significant part of emissions could be reduced by implementing approaches focusing on sustainable aviation fuel (SAF) implementation (34%) in its flights and, secondly, on technology improvements (32%), which, as mentioned before, have been regarded as essential drivers in pursuing a successful decarbonization path according to ICAO (*Section 2.6.2* and *2.6.3*).

Regarding FY2023, Ryanair disclosed a further reduction in its emission intensity, which decreased to 66 gCO_2 pax/km, compared to 76 gCO_2 pax/km recorded in 2022. Further, to contribute to the achievement of the 1.5°C degrees Paris Agreement's goal, the airline introduced a new short-term emission intensity target and amended an existing one, consisting of:

- reaching 5% emission intensity reduction by FY2026 (i.e., 63 gCO_2 per pax/km);
- reaching 25% emission intensity reduction by FY2031 (i.e., 50 gCO_2 per pax/km), which was previously set at 10% (i.e., 60 gCO_2 per pax/km) (Ryanair, 2023).

The targets mentioned above are also represented in Figure 18.

Fleet renewal As part of its fleet renewal strategy, Ryanair has planned the delivery of brand-new Boeing 737s by the American aircraft manufacturer Boeing, that will replace older aircraft. In particular, from FY2022 to FY2025, Ryanair plans to receive 210 new Boeing 737-8200 aircraft, and subsequently, from FY2027 to FY2034, it will receive 300 new Boeing 737-MAX-10 aircraft (Ryanair, 2023).
The new Boeing 7377-8200 and 737-MAX-10 aircraft are characterized by improved efficiency and better environmental performance, thanks to the new Scimitar Winglets incorporated and their fuel-efficient and quieter engines, capable of delivering up to 20% reduction in fuel

use and emissions, while resulting in 50% quieter compared to its antecedent models that they are replacing in Ryanair fleet (Ryanair, 2023).

New technology: Scimitar Winglets Scimitar Winglets are innovative technological winglets capable of reducing fuel consumption, take-off noise, and NO_x emissions when implemented in aircraft. In particular, these new winglets enable aircraft to be up to 1.5% more fuel-efficient, less noisy during the take-off phase for at least 6.5%, and reduce NO_x emissions by up to 8%, primarily thanks to their lighter weight (Ryanair, 2023). As part of its technological innovation measures, Ryanair expects to modernize 409 Boeing 737-800NGs of its fleet as part of the agreement signed with APB in the first half of FY2023 (Ryanair, 2023). Concerning the end of the current FY2023, Ryanair declared that it has installed the Scimitar Winglets in 18 Boeings of its fleet and plans to retrofit more than 70 aircraft by the end of FY2024 (Ryanair, 2023).

Sustainable Aviation Fuel (SAF) As previously mentioned, implementing SAF is regarded as one of the most influential and realistic drivers for successfully attaining the aviation sector's decarbonization by 2050. Ryanair supports this theory, and as illustrated by Figure 18, it plans to pursue its decarbonization pathway by reducing 34% of its emissions by employing an increasing amount of sustainable aviation fuel (SAF).
As early as 2022, the low-cost airline company signed a Memorandum of Understanding with Shell, Repsol, and OMV prescribing up to 675,000 mt of SAF's supply, planned to be delivered within the Group's most significant locations in Europe (Ryanair, 2023). Further, Ryanair ambitiously expects to reach the 12.5% SAF's implementation by 2030 (Ryanair, 2023). Among the actions undertaken within its business, Ryanair is also actively supporting the European Commission, national governments, the Fuelling Flight Project[24], and fuel suppliers to stimulate the production and deployment of SAF, as well as reducing the challenges that are currently hindering SAF's diffusion, such as its uncompetitive price (SAF is far more expensive compared to kerosene), the limited feedstock availability, and the high investment costs related to SAF's commercialization (Ryanair, 2023).

Air traffic management Ryanair claims that enabling more efficient traffic management would efficiently reduce 10% of emissions, allowing the low-cost airline to reach its net zero target by 2050. In particular, the airline actively sustains the "Single European Sky

[24]The Fuelling Flight program is an initiative undertaken by the European Climate Foundation (ECF) and ClimateWorks Foundation (CWF). The following program aims to deliver guidance concerning the sustainability considerations within the European Union's policy framework that encourages the employment of Sustainable Aviation Fuels (SAF) (ECF, 2021).

(SES)" ATM project (*Section 2.6.5*), which is argued to be capable of substantially reducing both CO_2 and non-CO_2 aviation-related emissions. Further, in 2023, the airline enacted its petition denominated as *"Protect Passengers – Keep EU Skies Open"*, seeking the European citizens' support in proposing the integration of this initiative into European Legislation (Ryanair, 2023). The initiative's plan consists of allowing 100% of overflights during strike action periods to avoid unnecessary emissions caused by aircraft that are obliged to prolong their flights to avoid closed airspaces. Ryanair declared that it has received support from more than 1 million citizens, enabling the company to present its petition to the European Commission in May 2023 (Ryanair, 2023).

EU Emission Trading System opposition Ryanair recalled its opposition to the limited extension of the European Emission Trading System (ETS) scheme for aviation, which comprises in its scope only intra-European flights, excluding thus long-haul flights from or to non-European countries. In particular, the airline company points out that exempting long-haul flights departing from European airports and arriving in non-European countries from the EU ETS application would exclude more than 50% of European air traffic emissions, which will be thus not paid nor considered under the EU ETS mechanism (Ryanair, 2023). In light of that, the airline company advocates, along with the NGO Transport & Environment, the expansion of the geographical scope of the current EU ETS mechanism, recalling the importance, in terms of climate impacts, of also covering long-haul flights departing from the European Economic Area (EEA) (Ryanair, 2023).

Carbon removals The low-cost airline company claims that 24% of its emissions could be reduced by 2050 by progressively supporting carbon offsetting and removal projects. In particular, Ryanair re-signed its active partnership with the "Renature Monchique" project (Ryanair, 2024), a Portuguese reforestation initiative aimed at offsetting the emissions stemming from the airline's flights, by planting 75,000 trees in the Algarve mountains to restore the Monchique's ecosystem previously destroyed by the 2018 wildfires (AlgarveDailyNews, 2022).

Internal carbon price Ryanair implements an internal carbon price based on EU ETS as part of its forecasts and budgetary procedures to evaluate the feasibility and the profitability of its projects and investment decisions (Ryanair, 2024). This internal carbon price is based on the EU ETS, as 85% of Ryanair's flights (intra-EU flights) fall under the EU ETS geographical scope. In light of that, considering the carbon price determined by the EU carbon market as an internal carbon price is crucial to assess the feasibility of the

Group's projects efficiently (Ryanair, 2023).

Sustainability Standards and Frameworks As part of its sustainability standards and frameworks Ryanair Holdings plc designed its Sustainability Report by incorporating the following standards:

- Sustainability Accouting Standards Board (SASB) industry-specific standards specifically designed for airlines;
- the Global Reporting Initiative (GRI) standards (in accordance with).

In addition, as of FY2025, Ryanard Holdings plc will be required to comply with the European Corporate Sustainability Reporting Directive (CSRD).
Furthermore, Ryanair Holdings plc disclosed in its Sustainability Report for 2023 the disclosures under Article 8 of the European Taxonomy Regulation (Regulation (EU) 2020/852), which requires the airline to disclose information relative to its Key Performance Indicators (KPIs) regarding its share of taxonomy-eligible economic activities. According to Commission Delegated Regulation (EU) 2021/2139, Annex I and Annex II economic activities have been analyzed by Ryanair Holdings plc's management. However, considering the Delegated Regulation in force during the reporting period 2023, the economic activity "air transport of passengers" does not fall under the scope of such legislation. Therefore, the disclosures relative to CapEx, OpEx, and Turnover KPIs for Ryanair Holdings plc for FY2023 all exhibit a share equal to 0% (Ryanair, 2023). However, since 1st January 2024, the new Draft Delegated Regulation (EU) 2023/2485 has entered into force (EC, 2023), extending its application to aviation-related economic activities, such as those relevant to airlines listed in Section 6.19. "Passenger and freight air transport", which have been closely scrutinized in *Section 2.5.2* (EC, 2023).

As tied to the previous *Section 2.4.1* of this work, we will analyze the SASB standards provided data related to the environmental sustainability dimension of the low-cost airline Ryanair Holdings plc for FY2023 compared to the ones of FY2022.

Topic	*Accounting metric*	*Category*	*Unit of measure*	*Code*	**FY2023**	**FY2022**
Greenhouse gas emissions	Gross global Scope 1 emissions	Quantitative	Metric tonnes (t) CO_2e (millions)	TR-AL-110a.1	14.3	9.1
	Discussion of long-term and short-term strategy or plan to manage Scope 1 emissions, emissions reduction targets, and an analysis of performance against those targets		n/a	TR-AL-110a.3	Discussed below	-
	(1) Total fuel consumed	Quantitative	USG[25] (Millions)	TR-AL-110a.3	1,484	952
	(2) Percentage alternative	Quantitative	Percentage (%)		Not disclosed	Not disclosed
	(3) Percentage sustainable	Quantitative	Percentage (%)	TR-AL-310a.1	Not disclosed	Not disclosed
Labour practices	Percentage of active workforce covered under collective bargaining agreements	Quantitative	Percentage (%)	TR-AL-310a.1	95%	89%
	(1) Number of work stoppages and (2) Total days idle	Quantitative	Number, days	TR-AL-310a.2	0	0
Competitive behaviour	Total amount of monetary losses as a result of legal proceedings associated with anticompetitive behaviour regulations	Discussion and analysis	Euro (millions)	TR-AL-540a.1	Zero	Zero
Accident and safety management	Description of implementation and outcomes of a safety management system	Discussion and analysis	n/a	TR-AL-540a.1	-	-
	Number of aviation accidents			TR-AL-540a.2	Not disclosed	Not disclosed
	Number of governmental enforcement actions of aviation safety regulations			TR-AL-540a.3	Not disclosed	Not disclosed

Table 6: SASB Sustainability Disclosure Topics & Accounting Metrics for Airlines relative to the Ryanair Group Sustainability Report's for FY2023 compared to FY2022. (Source: easyJet plc's Annual Report and Accounts, FY2023 and FY2022)

By observing the first "Greenhouse gas emissions" topic in Table 6, the first accounting metric requires the company to disclose its **gross global Scope 1 emissions**, consisting of all the greenhouse gas emissions stemming directly from the sources managed and owned by the airline while excluding the carbon removals, generated during its reporting period, expressed in millions of metric tonnes CO_2e.

In the case of Ryanair Holdings plc, the company has been accountable for the emission of 14.3 millions metric tonnes CO_2e in FY2023, displaying a 57.14% increase compared to FY2022 (amounting to 9.1 millions of metric tonnes CO_2e). Analogous to the case of the other low-cost airline, easyJet plc, such a substantial surge in emissions results correlated to the ongoing increase in air travel demand experienced in the last few years. In particular, by closely scrutinizing the *"Activity metric"* column illustrated in Table 7, we can observe that the activity metrics "Available Seat Kilometers (ASK)", "Revenue Passenger Kilometers (RPK)", and "Number of departures" all exhibited non-negligible increases.

- **Available Seat Kilometers (ASK)** have been recorded amounting to 229,698 (Millions) in FY2023 compared to 147,028 (Millions) in FY2022, exhibiting a 56.23% in-

[25]"USG" stands for "US Gallon".

crease.

- **Revenue Passenger Kilometers (RPK)** have increasedup to 213,619 (Millions) in FY2023, resulting 77.18% greater than the RPK recorded in FY2022.

- **Number of departures**, representing the number of flights operated by the airline, displayed a 52.56% increase in FY2023 compared to FY2022.

The accounting metric *"Discussion of long-term and short-term strategy or plan to manage Scope 1 emissions, emission reduction targets, and an analysis of performance against those targets"* requires the airline to disclose qualitative information concerning its sustainability strategies pursued to mitigate its Scope 1 emissions and its relative short- and long-term targets laid down. For FY2023, Ryanair's sustainability approaches and objectives relative to Scope 1 emission mitigation are discussed in the previous paragraph *"Ryanair Holdings plc and Sustainability"*.

The last three rows related to the "greenhouse gas emissions" topic regard fuel consumption, in particular (1) requires the airline to indicate the total amount of fuel utilized, and (2) and (3) the percentage of alternative fuel and sustainable aviation fuel (SAF) employed.

- Ryanair Holdings plc disclosed that its total fuel consumption amounted to 1,484 Million USG (US Gallons) in FY2023, consuming 55.88% more fuel than FY2022. In addition, unlike easyJet plc, Ryanair Holdings plc disclosed its fuel consumption in USG rather than Gigajoules. Such an enormous surge in fuel consumption proves once again to be related to the increase in air travel demand experienced in the last few years.

- Ryanair did not disclose the percentage of alternative or sustainable aviation fuel (SAF) employed in FY2023 and FY2022. Considering that the airline expects to reduce its emissions the most by utilizing SAF (34% in Figure 18) and despite the company precisely delineating its plan targets related to SAF's utilization, such non-disclosure might not reflect Ryanair's genuine commitment to its climate transition pathway.

Activity metric	*Category*	*Unit of measure*	*Code*	**FY2023**	**FY2022**
Available Seat Kilometers (ASK)	Quantitative	ASK (Millions)	TR-AL-000.A	229,698	147,028
Passenger load factor	Quantitative	Rate	TR-AL-000.B	93%	82%
Revenue Passenger Kilometers (RPK)	Quantitative	RPK (Millions)	TR-AL-000.C	213,619	120,563
Revenue Tonne Kilometers (RTK)	Quantitative	RTK	TR-AL-000.D	Not disclosed	Not disclosed
Number of departures	Quantitative	# (Number)	TR-AL-000.E	946,643	620,524
Average age of fleet	Quantitative	Years	TR-AL-000.F	9 years	8 years

Table 7: SASB Activity Metrics for Airlines relative to the Ryanair Group's Sustainability Report for FY2023 compared to FY2022. (Source: Ryanair Group's Sustainability Report, FY2023 and FY2022)

3.2 Legacy Airlines: Deutsche Lufthansa AG and KLM Dutch

3.2.1 Deutsche Lufthansa AG

The Deutsche Lufthansa AG, or Lufthansa Group, is one of the leading global airlines, making it the fourth-largest airline company by revenue worldwide. It incorporates several subsidiaries (airlines), which comprise both "Passenger Airlines" and "Aviation Services segments" (e.g., cargo transport), enabling the creation of both a passenger and cargo services network of services. Lufthansa is the leading airline of the Group, making it the largest airline in Europe. In particular, as part of the "Passenger Airlines" segment, other than the leading German Lufthansa airline, the Group also incorporates Swiss International Air Lines, Austrian Airlines, Brussels Airlines, and Eurowings as subsidiary airlines, plus the regional airlines Lufthansa CityLine, Lufthansa City Airlines, Air Dolomiti, Edelweiss Air, and Discover Airlines (Lufthansa, 2024b).
Through its "multi-hub strategy", Lufthansa Group aspires to offer its customers a "premium experience" by delivering "high-quality products and services" and by creating a network capable of connecting significant cities around the globe while ensuring flexibility for its passengers (Lufthansa, 2024b). As part of its company description, the airline group emphasizes its efforts undertaken in modernizing its fleet, outlining how the capital expenditure in replacing older and less fuel-efficient aircraft with new-generation ones capable of delivering less emissions and equipped with fuel-efficient and quieter engines results in the most crucial and promising step in reducing the airline carbon footprint.

To analyze how Lufthansa Group has addressed sustainability concerns regarding the environmental pillar, we will scrutinize its latest Sustainability Report, delineated in its Sustainability 2023 - Fact sheet (Lufthansa, 2023d) and Annual Report for FY2023 (Lufthansa, 2023a) relative to the period from 1 January 2023 to 31 December 2023.

Deutsche Lufthansa AG and Sustainability As part of its sustainability reporting for 2023, Deutsche Lufthansa AG emphasized how the sumptuous increase in air travel demand is persisting, recalling that it will strive *"to connect people, cultures, and economies in a sustainable way"* while *"making every effort to minimize environmental impact of flying"* (Lufthansa, 2023d). In particular, like all the airlines in the aviation industry, Lufthansa focuses on reaching the decarbonization climate target by 2050 and reducing by 30.6% its emission intensity relative to 2019 by 2030. The climate target for 2030 was approved by the Science Based Target initiative (SBTi) in 2022, resulting in compliance with the Paris Agreement temperature target (Lufthansa, 2023d). In the reporting year 2023, the Lufthansa Group's advancement towards its 2030 CO_2 emission intensity reduction target still resulted in progress, recording a 2.7% drop in emission intensity below 2019 levels (Lufthansa, 2023b), having 8 years to achieve a further 27.9% reduction in net emissions to accomplish its 30.6% reduction target. The increment in the "Passenger load factor" (Table 9), which increased from 79.8% to 82.9% in 2023, and the improvements in air traffic management have been the chiefly responsible factors for determining the achievements in emission intensity reduction in the prior recent years.

As mentioned earlier, the German Group of airlines intends to pursue these climate targets by mainly renewing its fleet and investing a significant part of its capital in ordering newer, more fuel-efficient, less pollutant aircraft. Alongside the fleet renewal strategy, Lufthansa plans to expedite the reach of its climate targets also by fostering the employment of sustainable aviation fuel (SAF), establishing partnerships and agreements with entities or projects promoting next-generation innovative technologies to reduce CO_2 emissions, and encouraging more sustainable cabin practices onboard.

Deutsche Lufthansa AG declared in its report to pursue the achievement of its climate targets by applying the 2007 ICAO's "four-pillar strategy of actions" designed to reduce CO_2 emissions (Lufthansa, 2023c), consisting in four different areas of action focused on implementing improvements in

1. *Technology* (i.e., new-generation aircraft and aircraft engine, SAF implementation),
2. *Operations* (i.e., operational improvements to enable more efficient flight procedures),
3. *Infrastructure* (i.e., support to the Single European Sky (SES) program), and
4. *Socio-economic initiatives* (i.e., application of economic measures aimed at offsetting emissions, such as mandatory offsetting schemes (EU ETS and CORSIA schemes) and voluntary offset options).

Fleet renewal In 2023, Deutsche Lufthansa AG continued to modernize its fleet by disposing of 18 older and less-efficient aircraft and modernizing it with 29 more fuel-efficient aircraft for short and long-haul routes, delivering up to 30% less fuel consumption (Lufthansa, 2023d). Additionally, the airline expects to insert in its fleet an additional 250 new generation fuel-efficient aircraft (Lufthansa, 2023d). Among these new aircraft orders, we can spot the Airbus A320neo and A321neo, belonging to the well-known A320neo family, as well as the A350-900 designed for longer-haul routes from the same aircraft manufacturer, and the Boeings 787-9 and 777F, likewise employed in long-haul flights (Lufthansa, 2023d).

Noise reduction The Lufthansa Group has significantly reduced its noise footprint through its renewal fleet strategy, thanks to the new quieter aircraft such as Airbus A321neo and Boeing 787-9 welcomed into its fleet. In particular, the airline adopts the "ICAO Chapter 4 Noise Standard" as a benchmark for noise impacts (Lufthansa, 2023d). In addition to newer and quieter aircraft, the Group also undertook other initiatives to diminish its noise footprint, such as adhering to a new research project cast by the German Aerospace Center focused on minimizing noise impact, employing up to 37 specific approaches aimed at reducing noise, elaborating in collaboration with its subsidiary Austrian Airlines new flight procedures aimed at optimizing noise emissions and maintaining an active dialogue with relevant stakeholders bearing noise impact the most, such as people living near airports (Lufthansa, 2022c).

New technology: AeroSHARK and A320 Hydrogen Aviation Lab Lufthansa plans to coat its aircraft with a peculiar innovative varnishing designed to lessen aircraft air resistance as part of its technological enhancements. This coating is denominated "AeroSHARK", which functions as a "fuel-saving" coating for aircraft, enabling them to achieve up to 8,000 tonnes of fuel savings and over 25,000 tonnes of CO_2 savings per year (Lufthansa, 2023c). Lufthansa Technik and BASF Coatings GmbH elaborated this innovative type of coating. In the reporting year 2023, Lufthansa Group declared that they have finalized and refined the technology behind such fuel-saving coating, announcing the approval for its mass production and the already occurred implementation on 15 Boeing 777s (Lufthansa, 2023d).
Furthermore, the Group of airlines is currently supporting research surrounding hydrogen technology, which is capable of significantly reducing aviation's carbon footprint. In particular, in the previous reporting year 2022, Lufthansa claimed that it was funding innovative technologies with the foundation of the "CleanTech Hub" program since 2021 (Lufthansa, 2022c). Further, Lufthansa Technik, together with other partners, is leading a research project, the "A320 Hydrogen Aviation Lab", where innovative hydrogen technology projects are developed and tested (Lufthansa, 2022c).

Sustainable Aviation Fuel (SAF) In Lufthansa's 2023 sustainability report, the airline disclosed its contribution to a total of 43,628 tons of fossil CO_2 savings by employing sustainable aviation fuel (Lufthansa, 2023b)(Lufthansa, 2023d). By breaking down these CO_2 emission savings related to sustainable aviation fuel utilization, SAF direct combustion accounted for 39,195 tonnes of savings. At the same time, the indirect effect of SAF employment enabled upstream supply chain operations, such as production and transport, to contribute to the saving of 4,433 tonnes of CO_2 (Lufthansa, 2023d)(Lufthansa, 2023b).
Also, the German Group of airlines recently partnered with an initiative established by the World Economic Forum, the "First Movers Coalition" (Lufthansa, 2023d). The latter initiative progressively fosters SAF usage, setting a 5% target to be attained by 2030. In addition, the Group's Executive Board has unlocked more funds to be invested in SAF purchasing until 2026 (Lufthansa, 2023b).

Carbon Offsettings Starting in 2019, the Lufthansa Group undertook the climate protection initiative "myclimate", which aimed to offset the CO_2 emissions stemming from the airline's employees' business-related flights (Lufthansa, 2022b)(Lufthansa, 2024a). In FY2023, the Group was accountable for 74,545 tonnes of CO_2 savings thanks to such an initiative (Lufthansa, 2023c).

Voluntary Carbon Offsetting: "Green fares" As part of its environmentally sustainable strategy for the reporting year 2023, the Lufthansa Group extended, starting from February 2023, the options of the new voluntary carbon offsetting (VOC) schemes for its passengers by offering them the opportunity to directly contribute to the acquisition of Sustainable Aviation Fuel (SAF) for a 20% (due to its dizzying price compared to traditional jet fuel (i.e., kerosene)) and to invest in a "climate project portfolio" in different countries for a 80% amount, supporting long-term projects vaulted at reducing emissions and safeguard the environment (Lufthansa, 2023c)(Lufthansa, 2024a). These new green fares are available in the booking phase on the Lufthansa website for flights in "Economy Class" and "Business Class", where the contribution is finalized simultaneously with the flight ticket's payment. Additionally, Lufthansa and SWISS Airlines passengers can choose to offset their emissions through green fares in a second moment after having purchased the flight ticket by displaying the option directly onboard through the entertainment system monitors (Lufthansa, 2024a). In its sustainability report for FY2023 the German airline declared that 3% of its customers are willing to pay more for "green fares" in their tickets, amounting to over 850,000 bookings (Lufthansa, 2023d).

Sustainable cabin practices To properly incorporate sustainability into its onboard practices, Lufthansa Group disclosed in its previous sustainability report relative for FY2022 that it has implemented a comprehensive set of measures on waste management in cabin practices into its business, geared towards reducing waste generation and fostering a circular economy. In particular, in 2022, all of Lufthansa Group's subsidiaries under the "Passenger Airlines" segment fell under the airline's waste management practices, having the set of ambitious objectives of avoiding the usage of single-use plastic and aluminum packaging and tools in its cabin practices by 2025, and halving food waste stemming from short-haul flight routes compared to 2019 (Lufthansa, 2022a)(Lufthansa, 2022c). The Group's subsidiaries are currently widening the life cycle of its products on board by undertaking several initiatives; for instance, SWISS airline recycles and reuses the cosmetic products that are for sale onboard, Austrian Airlines derives synthetic crude oil by retrieving disposable plastic cups employed on its flights, and, further, several airlines are promoting the utilization of compostable and biodegradable packagings and tools onboard (Lufthansa, 2022c).

Sustainability Standards and Frameworks As part of its sustainability standards and frameworks Deutsche Lufthansa AG designed its Sustainability Report by incorporating the following standards:

- the Global Reporting Initiative (GRI) standards (with reference to);
- Sustainability Accouting Standards Board (SASB) industry-specific standards specifically designed for airlines;
- Task Force on Climate-related Financial Disclosures (TCFD) for reporting on climate risks and opportunities;
- Carbon Disclosure Project (CDP) reporting.

As tied to the previous *Section 2.4.1* of this work, we will analyze the SASB standards provided information and data related to the environmental sustainability dimension of the legacy Group of airlines Deutsche Lufthansa AG for FY2023 compared to the ones of FY2022.

Topic	*Accounting metric*	*Category*	*Unit of measure*	*Code*	**FY2023**	**FY2022**
Greenhouse gas emissions	Gross global Scope 1 emissions	Quantitative	Metric tonnes (t) CO_2e (Millions)	TR-AL-110a.1	26.82	23.2
	Discussion of long-term and short-term strategy or plan to manage Scope 1 emissions, emissions reduction targets, and an analysis of performance against those targets		n/a	TR-AL-110a.3	Discussed below	-
	(1) Total fuel consumed	Quantitative	Million tonnes of oil equivalent	TR-AL-110a.3	8.451	7.284
	(2) Percentage alternative	Quantitative	Percentage (%)		0.15 %	0.17%
	(3) Percentage sustainable	Quantitative	Percentage (%)	TR-AL-310a.1	0.15 %	0.17%
Labour practices	Percentage of active workforce covered under collective bargaining agreements	Quantitative	Percentage (%)	TR-AL-310a.1	76%	78%
	(1) Number of work stoppages and	Quantitative	Number, days	TR-AL-310a.2	5 hours (December)	1 day (end of July) 1 day (September) 1 day (October) 3 days (October)
	(2) Total days idle				Zero	Zero
Competitive behaviour	Total amount of monetary losses as a result of legal proceedings associated with anticompetitive behaviour regulations	Discussion and analysis	n/a	TR-AL-540a.1	Zero	Zero
Accident and safety management	Description of implementation and outcomes of a safety management system	Discussion and analysis	n/a	TR-AL-540a.1	-	-
	Number of aviation accidents			TR-AL-540a.2	1	Zero
	Number of governmental enforcement actions of aviation safety regulations			TR-AL-540a.3	Zero	Zero

Table 8: SASB Sustainability Disclosure Topics & Accounting Metrics for Airlines relative to the Lufthansa Group's Annual Report for FY2023 compared to FY2022. (Source: Lufthansa Group's Annual Report, FY2023 and FY2022)

By observing the first "Greenhouse gas emissions" topic in Table 8, the first accounting metric requires the company to disclose its **gross global Scope 1 emissions**. By observing such first accounting metric related to the Group's direct emissions, we can notice that the legacy airline Deutsche Lufthansa AG has been accountable for the emission of 23.2 millions metric tonnes CO_2e in FY2023, exhibiting a remarkable 68,26% increase compared to FY2021. Following the broad rise in air travel demand experienced by the whole commercial aviation sector, such a surge in emissions can be clearly attributed to an increase in the number of flights in the last years. This fact is indeed confirmed in the Sustainability Report (Fact sheet) of the Lufthansa Group relative to the reporting year 2023. In particular, the legacy group of airlines states that *"(...) demand rose again significantly in the year 2023 (...)"* (Lufthansa, 2023d), which *"(...) combined with an increase in capacity in 2023 reporting year"* inevitably *" (...) resulted in corrispondingly higher fuel consumption."* (Lufthansa, 2023d) and emissions. In particular, this can be inferred and confirmed by closely scrutinizing the *"Activity metric"* column illustrated in Table 9. We can observe that the activity metrics "Available Seat Kilometers (ASK)", "Revenue Passenger Kilometers (RPK)", and "Number of departures" all exhibited non-negligible increases.

- **Available Seat Kilometers (ASK)** amounted to 300,582 (Millions) in FY2023 compared to 259,381 (Millions) in FY2022, exhibiting a 15.88% increase.
- **Revenue Passenger Kilometers (RPK)** have increased up to 249,269 (Millions) in FY2023, exhibiting a remarkable increase of 20.4% compared to FY2022.
- **Number of departures**, representing the number of flights operated by the airline, displayed a discrete 14.49% increase in FY2023 compared to FY2022.

The qualitative accounting metric *"Discussion of long-term and short-term strategy or plan to manage Scope 1 emissions, emission reduction targets, and an analysis of performance against those targets"* requires Lufthansa Group to drawn up an explanatory transcript of all the sustainability measures implemented to mitigate its Scope 1 emissions and the relative set up of its short- and long-term targets. For FY2023, Lufthansa Group's sustainability approaches relative to Scope 1 emission mitigation are discussed in the previous paragraph *"Deutsche Lufthansa AG and Sustainability"*.

The last three rows related to the "greenhouse gas emissions" topic regard fuel, in particular (1) demands the Group of airlines to indicate the total amount of fuel utilized, and (2) and (3) the percentage of alternative fuel and sustainable aviation fuel (SAF) employed.

- Deutsche Lufthansa AG claims that it had consumed a totality of 8.451 Million tonnes of oil equivalent in FY2023, exhibiting a surge equal to 16.02% of fuel consumed compared to FY2022; this relative remarkable surge in fuel consumption has been outlined in the Lufthansa Group's Sustainability Report for FY2023 and results also justified by the increase in air travel demand exemplified by the activity metrics in Table 9.
- Concerning the accounting metrics (1) and (2), Lufthansa Group claimed that in FY2022 it had utilized a share of 0.17% of Sustainable Aviation Fuel (SAF), while in FY2023 it declared a 0.15%, clearly displaying a 11.76% reduction in SAF utilization. However, despite such decrease, the Group of airlines declared roughly equal savings of CO_2 due to SAF employment in FY2023 (43,628 tonnes) (Lufthansa, 2023d) to the ones of FY2022 (43,900 tonnes) (Lufthansa, 2022c).

Activity metric	*Category*	*Unit of measure*	*Code*	**FY2023**	**FY2022**
Available Seat Kilometres (ASK)	Quantitative	ASK (Millions)	TR-AL-000.A	300,582	259,381
Passenger load factor	Quantitative	Rate	TR-AL-000.B	82.9%	79.8%
Revenue Passenger Kilometres (RPK)	Quantitative	RPK (Millions)	TR-AL-000.C	249,269	207,035
Revenue Tonne Kilometres (RTK)	Quantitative	RTK	TR-AL-000.D	31,925	27,427
Number of departures	Quantitative	# (Number)	TR-AL-000.E	946,132	826,379
Average age of fleet	Quantitative	Years	TR-AL-000.F	13.4 years	13.1 years

Table 9: SASB Activity Metrics for Airlines relative to the Lufthansa Group's Annual Report for FY2023 compared to FY2022. (Source: Lufthansa Group's Annual Report, FY2023 and FY2022)

EU Taxonomy For the first time, Lufthansa Group performed the disclosure of the information pursuit to Article 8 of the EU Taxonomy Regulation (EU) 2020/852 in its Annual Report relative to the FY2023 in response to the extension of the applicability of taxonomy-eligibility prescribed by one of the latest amendments to the Climate Delegated Act (i.e., Delegated Regulation (EU) 2023/2485) to the relevant aviation industry economic activities. As mentioned earlier in *Section 2.5.2*, the new amendment includes in its scope "3.21. Manufacturing of aircraft", "6.18. Leasing of aircraft", "6.19. Passenger and freight air transport", and "6.20. Air transport ground handling operations" economic activities, according to which technical screening criteria are provided to verify the taxonomy-eligibility to substantial contribute to the "climate change mitigation (CCM)" objective and to perform disclosures of non-financial information accordingly.

Deutsche Lufthansa AG reported the information relative to Article 8 disclosures in its Annual Report 2023 (Lufthansa, 2023a). After a dutiful analysis, the Group concluded that its core business activities are solely concerned with the "climate change mitigation (CCM)" objective.

Lufthansa Group economic activities relevant for reporting are listed as follow:

- **3.21. Manufacturing of aircraft**
- **6.19. Passenger and freight air transport**
- 7.7. Acquisition and ownership of buildings

However, reporting regarding the alignment of the newly introduced aviation-related economic activities will be mandatory starting from the reporting year 2024. Thus, Lufthansa Group assessed only the eligible proportions of turnover, CapEx, and OpEx for "3.21. Manufacturing of aircraft" and "6.19. Passenger and freight air transport" activities without assessing the alignment.

For each economic activity concerned, Lufthansa Group calculated the proportion of Article

8 required KPIs: the proportion of turnover, CapEx, and OpEx that are taxonomy-eligible. For the purpose of this work and with consideration to the review undertaken in *Section 2.5.2*, we will closely scrutinize only aviation-related economic activities newly introduced by the Delegated Regulation (EU) 2023/2485.

Concerning the economic activity **"3.21. Manufacturing of aircraft"**, Lufthansa stated in its latest Annual Report that proportions of turnover, CapEx, and OpEx from the activities specified in section 3.21. of the Delegated Regulation (EU) 2023/2485 primarily derive from its segment "Lufthansa Technik AG", which provides *"technical aviation services relating to the manufacture, maintenance, repair, and overhaul (MRO) of aviation components"* (Lufthansa, 2023a). In particular:

- Taxonomy-eligible **turnover** stemming from the provision of technical aviation services performed by Lufthansa Technik AG amounts to EUR 4,250 million, equal to 12% of the airline's total revenue for FY2023.

$$\text{Turnover KPI} = \frac{4,250 \text{ million}}{35,442 \text{ million}} \times 100 = 11.991\% \approx 12\% \tag{3}$$

- Taxonomy-eligible **CapEx** associated with Lufthansa Group's MRO segment activities amounts to EUR 77 million, equal to approximately 2% of the airline's total CapEx for FY2023.

$$\text{CapEx KPI} = \frac{77 \text{ million}}{4,329 \text{ million}} \times 100 = 1.779\% \approx 2\% \tag{4}$$

- **OpEx** directly incurred to operate the taxonomy-eligible economic activities performed by Lufthansa Group's MRO segment amounts to EUR 51 million, representing roughly 2% of the Group of airlines' total OpEx for FY2023.

$$\text{OpEx KPI} = \frac{51 \text{ million}}{2,846 \text{ million}} \times 100 = 1.792\% \approx 2\% \tag{5}$$

Regarding the Lufthansa Group's **"6.19. Passenger and freight air transport"** core business economic activity, the German Group of airlines claimed in its Annual Report that shares of turnover, CapEx, and OpEx connected to the activities specified in section 6.19. of the Delegated Regulation (EU) 2023/2485 are generated from its "Passenger Airlines" and "Logistics" business segments (Lufthansa, 2023a). In particular:

- Taxonomy-eligible **turnover** stemming from the provision of air traffic services performed by Lufthansa Group amounts to EUR 29,926 million, equal to 84% of the airline's total revenue for FY2023.

$$\text{Turnover KPI} = \frac{29,926 \text{ million}}{35,442 \text{ million}} \times 100 = 84.437\% \approx 84\% \quad (6)$$

- Proportion of **CapEx** associated to "6.19. Passenger and freight air transport" consists of all the expenditures related to aircraft and aircraft engines. Taxonomy-eligible CapEx amounts to EUR 3,788 million, equal to approximately 88% of the Lufthansa Group's total CapEx for FY2023.

$$\text{CapEx KPI} = \frac{3,788 \text{ million}}{4,329 \text{ million}} \times 100 = 87.503\% \approx 88\% \quad (7)$$

- Proportion of **OpEx** incurred to operate the "Passenger Airlines" and "Logistics" segments of Lufthansa Group amounts to EUR 2,601 million, representing 91% of the Group's total operational expenses.

$$\text{OpEx KPI} = \frac{2,601 \text{ million}}{2,846 \text{ million}} \times 100 = 91.391\% \approx 91\% \quad (8)$$

While the Group did not evaluate the alignment for these two newly introduced economic activities, it assessed the alignment for the activity "7.7. Acquisition and ownership of buildings" according to the technical screening criteria provided by the Climate Delegated Act.

The tables 10, 11, and 12 represented below illustrate how Deutsche Lufthansa AG's proportions of each KPI results as taxonomy-eligible and/or aligned.

Turnover KPI (%)

Objectives	**Activities**	**Taxonomy-aligned**	**Taxonomy-eligible**
CCM	**3.21.**	-	12% (4,250m)
	6.19.	-	84% (29,926m)
			Total turnover (taxonomy-eligible not aligned) 96% (34,176m)

Table 10: Proportions of turnover associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by Deutsche Lufthansa AG in FY2023. (Source: Lufthansa Group's Annual Report 2023)

CapEx KPI (%)

Objectives	**Activities**	**Taxonomy-aligned**	**Taxonomy-eligible**
CCM	**3.21.**	-	2% (77m)
	6.19.	-	88% (3,788m)
	7.7.	-	5% (236m)
			Total turnover (taxonomy-eligible not aligned) 95% (4,101m)

Table 11: Proportions of CapEx associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by Deutsche Lufthansa AG in FY2023. (Source: Lufthansa Group's Annual Report 2023)

OpEx KPI (%)

Objectives	**Activities**	**Taxonomy-aligned**	**Taxonomy-eligible**
CCM	**3.21.**	-	2% (51m)
	6.19.	-	91% (2,601m)
	7.7.	-	6% (158m)
			Total turnover (taxonomy-eligible not aligned) 99% (2,810m)

Table 12: Proportions of OpEx associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by Deutsche Lufthansa AG in FY2023. (Source: Lufthansa Group's Annual Report 2023)

3.2.2 KLM Royal Dutch Airlines

Airline description KLM Royal Dutch Airlines is a Dutch Group of airlines established in October 1919 and headquartered in Amstelveen, in the northern part of The Netherlands. It is one of the oldest Group of airlines in existence today, and its company name has remained unchanged since then (KLM, 2024b). The Dutch Group operates passenger and cargo transport services, functioning as a pivotal connector between central economies and communities worldwide thanks to its network, enabling connections to at least 92 European and 70 intercontinental countries (KLM, 2024b). Further, the Dutch Group of airlines expanded its domain by entirely incorporating Transavia and Martinair as its subsidiary airlines. In 2004, KLM Royal Dutch Airlines merged with AirFrance, a leading French airline, establishing the "AirFrance-KLM Group", becoming thus a subsidiary of the latter Group alongside its subsidiaries (Transavia and Martinair) and AirFrance itself. The AirFrance-KLM Group focuses on providing passenger and cargo services as their primary services, as well as engineering and maintenance activities (KLM, 2024b). KLM Royal Dutch Airlines claims that it is pursuing its sustainable development strategy at the Amsterdam Airport Schipol, an international airport where the airline is established, endeavoring to finalize its network quality and create value for its stakeholders (KLM, 2024b).

To investigate how the Dutch airline company KLM Royal Dutch Airlines is approaching sustainability concerns regarding the environmental dimension, we will scrutinize its Annual Report 2023 (KLM, 2023) relative to the period from 1 January 2023 to 31 December 2023.

KLM Royal Dutch Airlines and Sustainability KLM Royal Dutch Airlines exhibited a high commitment to sustainability in its Annual Report for FY2023. In its "Strategy" section of the report, the Dutch Group of airlines first underscores that *"the airline industry needs to become more sustainable"* (KLM, 2023), affirming its commitment to pursue a decarbonization path by 2050 in line with the European Green Deal targets and the IATA's ambitious goal by predominantly dedicating a large part of its investments to fleet renewal strategy and by establishing stricter requirements for sustainable aviation fuel (SAF) utilization.

The sustainability plan of KLM Royal Dutch Airlines results articulated in three specific achievements: *"1. to run a great airline for our customers and our people, 2. to create technological advancement, and 3. to improve for the future"* (KLM, 2023), summarized in the airline's overall intention to significantly reduce its impact on the environment while creating positive value for its stakeholders.

In particular, as a result of the merger with the French airline AirFrance finalized in 2004, in 2022, the two European airlines established a set of climate targets entirely in line with the Science Based Target Initiative (SBTi), which began to be effectively incorporated into the business since the beginning of 2023 (KLM, 2023). KLM Royal Dutch Airlines and AirFrance established the following climate targets to be attained by 2030:

- a relative 30% reduction target in gr CO_2 per Revenue Tonne Kilometers (RTK) compared to 2019 (corresponding to a reduction of 871 gr CO_2 emissions per RTK)

- an absolute 12% reduction target in ktons CO_2 compared to 2019 (corresponding to a reduction of 12.03 Mt CO_2 emissions)

- achievement of 10% of SAF utilization;
- reduce to 0 its ground operations by employing mainly electric vehicles;
- halving its non-separated waste compared to 2011 (corresponding to a reduction of 12,980 metric tons).

Whereas for the 2050-year deadline, the Dutch Group of airlines endeavors to follow its commitment to the IATA's decarbonization target by reaching 0 of total CO_2 emissions (KLM, 2023).
In addition to the climate plan established with AirFrance, KLM established the *"Cleaner, quieter, and more efficient"* plan, which focuses on reducing the airline's noise footprint. The plan is intended to be applied within The Netherlands and has been submitted to the Dutch government in mid-2023.

Concerning the results obtained in the reporting year 2023, KLM disclosed that it has been accountable for 10,132.7 ktons of CO_2eq of direct emissions (Gross Scope 1 emissions) (KLM, 2023), 11.35% greater than the previous year, mainly due to the increase experienced in air travel demand.
As part of its decarbonization strategy, KLM claimed that, like most airlines and in line with IATA's reports, investments in new aircraft fuel-efficient and quieter aircraft, increasing implementation of SAF, and advancements in technology to explore zero aviation technologies are the actions that have the highest potential to effectively reduce the largest portion of emissions and successfully achieve the airline's climate targets and the IATA's decarbonization goal by 2050. On the other hand, strategies related to operational improvements, sustainable cabin practices, and collaboration with other aviation stakeholders are believed to deliver emissions reductions ranging from 2% to 4% of the total Dutch airline's emission reduction target, playing the least impactful role in reducing emissions (KLM, 2023).

Fleet renewal KLM Royal Dutch Airlines is focusing a considerable part of its resources on modernizing its fleet with more fuel-efficient and quieter aircraft, deeming fleet renewal one of the most effective strategies for pursuing its climate targets.
In particular, the airline declared that it will include 25 brand-new Embraer 195-E2 aircraft in its fleet, of which 18 have already been delivered. The new Embraer 195-E2 aircraft are replacing the Embraer 190 of KLM Royal Dutch Airlines' fleet for short and medium-haul flights, and these new aircraft are capable of delivering 30% less emission intensity compared to the Embraer 190 that they replace. Further, the Group plans to welcome the well-known A320neo and A321neo aircraft intended to replace older Boeing 737s, of which one A321neo

currently operates under the KLM's subsidiary Transavia since the end of 2023. The Airbus and the Embraer aircraft comprehensively enable KLM to have a 50% quieter fleet than its older employed aircraft. Concerning long-haul flights, the Dutch company has ordered 50 brand-new Airbus A350s, which consume 25% less fuel, resulting in more fuel-efficient than the Boeing 777s they will replace. KLM also focused on fostering its sustainability reputation by replacing its old freighters, which is deemed as a fundamental step towards achieving its emission intensity target by 2030. In particular, the Group of airlines is replacing its Boeing 747-400 for cargo operations with a new A350F, which is expected to have the capability of delivering a 40% reduction in CO_2 emissions.

Noise reduction As part of its sustainability approach, KLM Royal Dutch Airlines has submitted, as mentioned before in the *"KLM Royal Dutch Airlines and Sustainability"* paragraph, the *"Cleaner, quieter, and more efficient"* plan to the Dutch government. This plan chiefly endeavors to significantly reduce the Dutch airline noise impact by following two specific strategies: *"Further investment in new, cleaner, and quieter aircraft"*, *Improving quality of life in the surroundings of Schiphol"*, and *"Flying smarter and quieter"* (KLM, 2023). As mentioned earlier, KLM Royal Dutch Airlines is considerably relying on its fleet renewal strategy by proceeding with the orders and deliveries of new-generation aircraft, such as the Embraer 195-E2 and the A320neo and A321neo aircraft, to unlock more fuel efficiency as well as a lower noise footprint. These two new type of aircraft, indeed, are capable of delivering 50% less noise than the ones they are replacing. Further, KLM seeks to serve its quieter aircraft in the fleet for flights operated at night by adjusting flight schedules accordingly to reduce noise disturbance further. Another significant step that KLM took is enabling noise reduction by charging additional airport taxes for louder aircraft that are landing or departing from the Schiphol Airport (KLM, 2023). Regarding the second strategy, KLM is committed to significantly reducing noise disturbance for residents near Schiphol Airport. The effective achievement of this strategy's goal can be unlocked through the pursuit of a dedicated cooperative approach with the Air Traffic Control of the Netherlands (LVNL) and the airlines operating at Schiphol Airport by demonstrating a solid commitment to minimizing the impact of noise on nearby residents via the execution of specific arrival and departure procedures (KLM, 2023). Furthermore, thanks to the fleet renewal strategy already in place, the totality of the KLM Royal Dutch Airlines' fleet proved to be compliant with Chapter 4 and Chapter 14 ICAO's noise requirements at the end of the reporting year 2023 compared to the previous FY2022, during which just 60% of the fleet satisfied the ICAO's noise requirements (KLM, 2023).

Sustainable Aviation Fuel (SAF) In its Annual Report for 2023, KLM Royal Dutch Group demonstrated ambitious expectations and requirements for Sustainable Aviation Fuel (SAF) utilization in its business. In particular, the Group claimed that it has strict requirements for the percentage of Sustainable Aviation Fuel (SAF) that has to be "blended" with traditional jet fuel (i.e., kerosene) in its flights. As part of its requirements, the Dutch airline demands compliance with the emission reduction requirement of delivering "at least 75% less CO_2 over the fuel life cycle" (KLM, 2023) and, as mentioned in the *"KLM Royal Dutch Airlines and Sustainability"* paragraph, the global percentage requirement of 10% of SAF blended with kerosene that has to be satisfied by 2030 (KLM, 2023). Peculiarly from other airlines in the industry, KLM Royal Dutch Airlines, together with AirFrance, has implemented a particular surcharge fee on all the flights departing from the Amsterdam Schiphol Airport amounting to 1%, which is intended to be entirely dedicated to SAF purchasing, in response to the challenging market prices of sustainable aviation fuel (KLM, 2023). Concerning what has been done, KLM Royal Dutch Airlines declared in its Annual Report for FY2023 that it had reached 1.2% of SAF blending voluntarily, which results as one of the best-achieved outcomes concerning SAF utilization compared to other airlines in the industry. Therefore, thanks to its solid commitment to boosting SAF utilization, KLM has already achieved notable outcomes in emissions savings in the last reporting year. In particular, KLM saved up to 179 ktons of CO_2eq by increasingly blending SAF, exhibiting a considerable 105.75% increase in CO_2 savings through SAF usage compared to FY2022 (KLM, 2023).

New technology: "Zero Emission Aviation Programme" Exploring new aviation technology focused on producing zero-emission engine aircraft is pivotal to supporting and enabling future decarbonization. For such reason, the Dutch airline disclosed the startup of *"Zero Emission Aviation"*, an innovative program aimed at fostering modernization and sustainability in next-generation aircraft by developing new electric, hydrogen, or hybrid propulsion systems (KLM, 2023). The Group also strictly cooperates with several start-ups, manufacturers, and regulators to provide solid support for elaborating new technologies.

Electrified ground support equipment (GSE) To assure the fulfillment of its ambitious goal to reach zero emissions from ground operations by 2030, KLM is increasingly promoting the electrification of its handled vehicles for ground operations at its base airport in Amsterdam, the Schiphol Airport. Through this strategy, the Dutch company will reduce its CO_2 emissions while improving air quality for its ground operators and employees. At the end of FY2023, KLM claimed it had reached 68% of electrified ground supporting equipment

(GSE) (KLM, 2023).

Operational improvements Regarding operational refinements, KLM stated that, in the current reporting year, it has commenced adopting operational measures aimed at inhibiting flying at high speeds due to the higher quantity of fuel that flying at such speeds requires compared to traditional average speed.

Airspace modernization KLM Royal Dutch Airlines, along with other partner airlines, continues to advocate for the Single European Sky (SES) initiative. In particular, the Dutch Group of airlines stated in its report its beliefs concerning the European project aimed at modernizing airspace management through the design of more efficient flight paths, believing that it could be able to deliver CO_2 emissions savings ranging from 6% to 10% (KLM, 2023).

Internal carbon price When it comes to investments related to fleet renewal, the Dutch airline carefully evaluates its decisions by incorporating an "internal carbon price mechanism" to effectively assess the environmental cost of carbon emissions related to each of the financial options it evaluates. Like many other airlines, KLM utilizes the market price in the carbon market registered at the beginning of each financial year as a reference price for its internal carbon price mechanism.

Sustainable cabin practices As mentioned earlier, KLM Royal Dutch Airlines has set as part of its set of climate targets the goal of cutting by half its non-hazardous, nonseparated waste (i.e., cabin waste generated durign inflight services) compared to quantities recorded in 2011, which amounted to 12,980 tons, by 2030 (KLM, 2023). Thus, to align with its target, the Dutch airline must produce at most 6,490 tons of cabin waste by 2030. To ensure the successful attainment of its waste-related climate target, KLM updated its waste management strategy at the beginning of the last reporting year (2023).

Voluntary Carbon Offsetting The Dutch Group of airlines offers its customers the possibility to voluntary invest in SAF purchasing or "carbon credits" to partially compensate for the CO_2 emissions deriving from their flights thanks to the establishment of the KLM's initiative "CO_2eq Impact Programme" (KLM, 2023)(KLM, 2024a).

EU Taxonomy Analogously to the case of the Deutsche Lufthansa AG's Annual Report, KLM Royal Dutch Airlines incorporated in its annual report (KLM, 2023) the evaluation of the mere eligibility of aviation-related economic activities covered by the new Delegated

Regulation (EU) 2023/2485 without assessing their alignment according to technical screening criteria provided by the Regulation. The assessment of the alignment of the economic activities prescribed by the last amendment of the Climate Delegated Act will be mandatory starting from the reporting year 2024.

KLM Royal Dutch Airlines thus reported the information relative to Article 8 disclosures in its Annual Report 2023 (KLM, 2023). After a dutiful analysis, KLM concluded that its core business activities are concerned with the "climate change mitigation" and the "pollution prevent and control" objectives (KLM, 2023).
KLM's economic activities relevant for reporting are listed as follow:

- 2.1. Collection and transport of hazardous waste
- **3.21. Manufacturing of aircraft**
- 4.15. District heating/cooling distribution
- 5.1. Construction, extension and operation of water collection, treatment, and supply systems
- 5.5. Collection and transport of non-hazardous waste in source segregated fractions
- 6.17. Low carbon airport infrastructure
- **6.19. Passenger and freight air transport**
- **6.20. Air transport ground handling operations**
- 6.5. Transport by motorbikes, passenger cars, and light commercial vehicles
- 7.1. Construction of new buildings
- 7.2. Renovation of existing buildings
- 7.3. Installation, maintenance, and repair of energy efficiency equipment
- 7.4. Installation, maintenance, and repair of charging stations for electric vehicles in buildings (and parking spaces attached to buildings)
- 7.5. Installation, maintenance, and repair of instruments and devices for measuring, regulation, and controlling energy performance of buildings
- 7.6. Installation, maintenance, and repair of renewable energy technologies

- 7.7. Acquisition and ownership of buildings
- 8.1. Data processing, hosting, and related activities
- 9.3. Professional services related to energy performance of buildings

For each of these economic activities, KLM Royal Dutch Airlines calculated the proportion of Article 8 required KPIs: the proportion of turnover, CapEx, and OpEx that are taxonomy-eligible and/or aligned. For the purpose of this work and with consideration to the review undertaken in *Section 2.5.2*, we will closely scrutinize only aviation-related economic activities newly introduced by the Delegated Regulation (EU) 2023/2485.

Concerning the economic activity **"3.21. Manufacturing of aircraft"**, KLM declared in its latest Annual Report the proportions of turnover, CapEx, and OpEx from the activities specified in section 3.21. of the Delegated Regulation (EU) 2023/2485. The proportions of taxonomy-eligible KPIs primarily stem from KLM's "maintenance contracts" and the maintenance activities involving aircraft in its fleet (KLM, 2023). In particular:

- Taxonomy-eligible **turnover** stemming from the establishment of maintenance contracts amounts to EUR 920.8 million, equal to 7.6% of the Dutch Group's total revenue for FY2023.
$$\text{Turnover KPI} = \frac{920.8 \text{ million}}{12,050.4 \text{ million}} \times 100 = 7.64\% \tag{9}$$
- Taxonomy-eligible **CapEx** associated with maintenance of aircraft activities amounts to EUR 495.5 million, equal to 49.2% of KLM's total CapEx for FY2023.
$$\text{CapEx KPI} = \frac{495.5 \text{ million}}{1,006.2 \text{ million}} \times 100 = 49.24\% \tag{10}$$
- **OpEx** directly incurred to operate the taxonomy-eligible economic activities associated with the "Manufacturing of aircraft" category amounts to EUR 1,350.7 million, representing 82.6% of KLM's total OpEx for FY2023.
$$\text{OpEx KPI} = \frac{1,350.7 \text{ million}}{1,634.5 \text{ million}} \times 100 = 82.64\% \tag{11}$$

Regarding the KLM's "6.19. Passenger and freight air transport" relevant business economic activity, the Dutch Group claimed in its Annual Report that shares of turnover, CapEx, and OpEx connected to the activities specified in section 6.19. of the Delegated Regulation (EU) 2023/2485 are generated from its "Group's Network and Leisure business", capital expenditures plus operational expenses related to its fleet (KLM, 2023). In particular:

- Taxonomy-eligible **turnover** stemming from the provision of air traffic services performed by KLM Royal Dutch Airlines amounts to EUR 10,691.0 million, equal to 88.7% of the Group's total revenue for FY2023.

$$\text{Turnover KPI} = \frac{10,691.0 \text{ million}}{12,050.4 \text{ million}} \times 100 = 88.71\% \tag{12}$$

- Proportion of **CapEx** associated to "6.19. Passenger and freight air transport" consists of all the expenditures related to the KLM Group's fleet. Taxonomy-eligible CapEx amounts to EUR 396.0 million, equal to roughly 39.4% of the Group's total CapEx for FY2023.

$$\text{CapEx KPI} = \frac{396.0 \text{ million}}{1,006.2 \text{ million}} \times 100 = 39.36\% \approx 39.4\% \tag{13}$$

- Proportion of **OpEx** incurred to operate the "Group's Network and Leisure business" amounts to EUR 158.5 million, representing 9.7% of KLM's total operational expenses.

$$\text{OpEx KPI} = \frac{158.5 \text{ million}}{1,634.5 \text{ million}} \times 100 = 9.7\% \tag{14}$$

In contrast to Lufthansa Group's strategy, KLM Royal Dutch Airlines is making significant efforts to promote the utilization of electric vehicles in its group operations. The ambitious goal of reaching zero ground operations emissions by 2030 outlines the Dutch company's intention to handle its ground operations in a more environmentally sustainable manner (KLM, 2023). For such reason, KLM's ground operations activities result as eligible under the "6.20. Air transport ground handling operations" section prescribed by the new Delegated Regulation (EU) 2023/2485. In particular:

- Taxonomy-eligible **turnover** stemming from KLM's ground operations amounts to EUR 155.4 million, equal to approximately 1.3% of KLM's total revenues.

$$\text{Turnover KPI} = \frac{155.4 \text{ million}}{12,050.4 \text{ million}} \times 100 = 1.29\% \approx 1.3\% \tag{15}$$

- Taxonomy-eligible **CapEx** associated to KLM's ground operations amounts to EUR 1.2 million, representing 0.1% of the Dutch Group's total capital expenditures.

$$\text{CapEx KPI} = \frac{1.2 \text{ million}}{1,006.2 \text{ million}} \times 100 = 0.12\% \tag{16}$$

- Taxonomy-eligible **OpEx** incurred to ensure the functioning and readiness of the Group's ground operations amount EUR 5.5 million, corresponding to 0.3% of KLM's total operational expenses.

$$\text{OpEx KPI} = \frac{5.5 \text{ million}}{1,634.5 \text{ million}} \times 100 = 0.336\% \approx 0.3\% \tag{17}$$

The tables 13, 14, and 15 represented below illustrated how the proportions of taxonomy-eligible and/or aligned KPIs are distributed for KLM Royal Dutch Airlines.

Turnover KPI (%)

Objectives	**Activities**	**Taxonomy-aligned**	**Taxonomy-eligible**
CCM	**3.21.**	-	7.6% (920.8m)
	6.19.	-	88.7% (10,691.0m)
	6.20.	-	1.3% (155.4m)
			Total turnover (taxonomy-eligible not aligned)
			97.7% (11,767.3m)

Table 13: Proportions of turnover associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by KLM Royal Dutch Airlines in FY2023. (Source: KLM Royal Dutch Airlines Annual Report 2023)

CapEx KPI (%)

Objectives	Activities	Taxonomy-aligned	Taxonomy-eligible
CCM	**3.21.**	-	49.2% (495.5m)
	4.15.	-	0.1% (1.3m)
	5.1.	0.3% (2.7m)	-
	6.5.	0.0% (0.4m) [T]	0.2% (1.6m)
	6.19.	-	39.4% (396.0m)
	6.20.	-	0.1% (1.2m)
	7.1.	-	1.0% (9.9m)
	7.2.	-	1.7% (17.5m)
	7.3.	0.6% (6.4m) [E]	-
	7.4.	0.0% (0.2m) [E]	-
	7.5.	0.1% (1.3m) [E]	-
	7.6.	0.1% (0.8m) [T]	-
	7.7.	0.0% (0.0m)	
	8.1.	-	0.5% (4.7m)
PCC	2.1.	-	0.1% (0.7m)
		Total CapEx (taxonomy-aligned)	**Total CapEx (taxonomy-eligible not aligned)**
		1.2% (12.0m)	92.2% (928.2m)

Table 14: Proportions of CapEx associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by KLM Royal Dutch Airlines in FY2023, where "[E]" denotes enabling activities and "[T]" transitional activities. (Source: KLM Royal Dutch Airlines Annual Report 2023)

OpEx KPI (%)

Objectives	Activities	Taxonomy-aligned	Taxonomy-eligible
CCM	**3.21.**	-	82.6% (1,350.7m)
	5.5.	0.0% (0.7m)	-
	6.19	-	9.7% (158.5m)
	6.20.	-	0.3% (5.5m)
	7.3.	2.7% (44.1m) [E]	-
	7.4.	0.1% (1.6m) [E]	-
	7.5.	0.6% (9.2m) [E]	-
	7.6.	0.4% (5.7m) [E]	-
	7.7.	0.0% (0.1m)	-
	9.3.	0.1% (1.2m) [E]	-
		Total CapEx (taxonomy-aligned)	**Total CapEx (taxonomy-eligible not aligned)**
		3.8% (62.6m)	92.7% (1,514.7m)

Table 15: Proportions of OpEx associated to taxonomy-aligned and/or taxonomy-eligible economic activities performed by KLM Royal Dutch Airlines in FY2023, where "[E]" denotes enabling activities and "[T]" transitional activities. (Source: KLM Royal Dutch Airlines Annual Report 2023)

KLM Royal Dutch Airlines emphasized in its latest Annual Report its intention to extend the mandatory alignment assessment to the newly introduced aviation-related activities by the Delegated Regulation (EU) 2023/2485 as of reporting year 2024. Further, the Dutch Group pointed out how the new fuel-efficient and quieter aircraft will play an essential role in the future alignment assessment of the new activities, as they are expected to successfully fulfill the prescribed EU Taxonomy's technical screening criteria and requirements.
By observing the tables 13, 14, and 15 represented above, we can notice that the economic activities introduced by the latest amendment to the Climate Delegated Act constitute a considerable portion of KLM's turnover, CapEx, and OpEx.

3.3 Airlines and Environmental Sustainability: Conclusions and Comparisons

By comparing the sustainability strategies embraced by these four airlines to reduce their emissions and cope with the climate emergency in the short- and medium-term, we can notice a familiar pattern. In particular, all four airlines put more weight and effort into strategies to modernize their fleet and promote SAF employment. This commonality aligns with what IATA declared, assessing fleet renewal and increasing SAF utilization as the strategies with the highest potential to pursue a successful decarbonization path while pending further advancements in next-generation technology (i.e., zero-emission and hybrid-electric aircraft) (see *Section 3.1.1*).

Low-cost Carriers Considering the group of low-cost carriers, easyJet plc aspires to reduce the prevalence of its emissions by 2030 by introducing new fuel-efficient and quieter aircraft into its fleet and, secondly, by increasingly adopting SAF in its flights, followed by airspace modernization and operational improvement strategies. The same holds for Ryanair Holdings plc, which, in its "Net Zero Path" to be pursued by 2050, depicts SAF utilization as the most promising strategy capable of reducing 34% of carbon emissions by 2050. This is followed by further improvements in aviation technology (also comprising fleet renewal), deemed to be capable of reducing 32% of emissions (see Figure 18). Among all airlines under analysis, the only airline not currently investing efforts in voluntary carbon offsetting schemes is easyJet plc. In 2022, it declared its intention to shift the resources previously employed in voluntary carbon offsetting to investments in technological innovation, regarded as one of the best decarbonization strategies for the aviation industry, especially in the long-run scenario. This statement also corroborates what was underscored in the previous *Section 2.6.4* about the debatable efficiency of "green fares" proposed by airlines to consumers, resulting in a decarbonization strategy delivering minimal results in terms of efficiency.

Legacy Airlines Concerning the legacy airlines group, by analyzing the Lufthansa Group Annual Report and its "Sustainability Fact-sheet" we can infer that the German Group aims to pursue its decarbonization path by predominantly undertaking fleet renewal strategy by welcoming more fuel-efficient aircraft in its fleet and, secondly, by increasing SAF adoption throughout also its partnership established with the "First Movers Coalition" initiative setting a 5% SAF utilization target by 2030 (see *Section 3.2.1*). Analogously to what was observed earlier, KLM Royal Dutch Airlines maintains that a considerable part of its emissions can be efficiently reduced by modernizing its fleet with fuel-efficient and less pollutant aircraft, increasing SAF utilization, and supporting further technological advancements in zero-emission aviation. The Dutch Group then claims that operational improvements and more sustainable cabin practices (i.e., circularity in waste management) result as the least promising strategies in reducing emissions, estimated to be capable of lowering solely from 2% to 4% of the airline CO_2 target (see *Section 3.2.2*). Regarding SAF utilization, KLM is undertaking noteworthy steps in terms of initiatives; for instance, the Dutch company, together with AirFrance as a result of their merger, is the first ever airline to impose a 1% fee designed to be invested in SAF purchasing to all the flights departing from the Amsterdam Schipol Airport.

Climate targets As part of their environmental sustainability strategy and net zero path to be pursued by 2050, each airline has set their climate targets accordingly to successfully align with the European Green Deal objectives and Paris Agreement temperature target. Upon analyzing the four Sustainability Reports, we can note that, other than the net zero targets by 2050 commonly settled by all airlines as required by IATA, they have voluntarily set their tailored mid-term targets for 2030 or earlier, setting 2019 as the baseline year in line with the Science Based Target initiative (SBTi). Table 16 illustrates all the targets established by each airline, the topic covered, the target deadline, and the goal to be attained.

Airline's Category	***Airline***	***Climate Target***	***Target Deadline***	***Goal***
Low-cost Carriers	**easyJet plc**	Emission intensity	2030	-35%
		Emission intensity	2050	-78%
	Ryanair Holdings plc	Emission intensity	2026	-5%
		Emission intensity	2031	-25%
Legacy Airlines	**Deutsche Lufthansa AG**	Emission intensity	2030	-30.6%
		SAF utilization	2030	5%
	KLM Royal Dutch Airlines	Emission intesity (RTK)	2030	-30%
		ktons CO_2	2030	-12%
		SAF utilization	2030	10%
		Ground emissions	2030	0
		Waste	2030 (2011 baseline)	-50%

Table 16: Climate targets set by each airline under analysis. All the targets involving CO_2 emission reductions utilize 2019 as the baseline year.

By scrutinizing the Table 16 illustrated above, we can notice that the legacy airline KLM Royal Dutch Airlines distinguishes itself among other airlines in terms of ambition in its climate targets. In particular, different from the other airlines under analysis, it has set a comprehensive set of climate targets covering more than one environmental concern area, ranging from emission intensity to SAF utilization and waste management. Then, both legacy airlines under analysis exhibit a strong commitment to nurturing SAF employment in their flights by fixing a percentage of SAF to be reached by 2030. Thanks to its notable progress in current SAF employment within its fleet, KLM Royal Dutch Airlines reached in FY2023 a percentage of SAF utilization equal to 1.2%, resulting in one of the highest rates in the aviation industry. Accordingly, this permitted the Dutch Group to set the challenging target of 10% of SAF utilization to be attained by 2030.

In conclusion, progressive SAF employment and fleet renewal result as the most promising decarbonization strategies from a short- and medium-term perspective, followed by offsetting mechanisms (voluntary and mandatory), airspace modernization (i.e., Single European Sky (SES) initiative and similar), and increased circularity in waste management. Instead, under a long-term vision, the commercial aviation industry claims that focusing on further technological advancements would deliver the best outcomes in finalizing emission reductions to reach the net zero target by 2050. In particular, technological innovation in the aviation industry promotes the development of zero-aviation aircraft, either powered by green hydrogen or hybrid/electric engines. For this reason, all four analyzed airlines exhibit their solid commitment to supporting technological innovation by investing in ground-breaking projects and establishing initiatives with leading aircraft manufacturers and other relevant stakeholders.

4 Survey: Consumers' awareness of sustainability concerns when taking flights

4.1 Methodology

4.1.1 Background

In the present era, where climate and sustainability concerns are increasing at an unprecedented rate, businesses have taken a central role in the global sustainability debate in response to increased end-users climate emergency awareness and sustainability expectations. Businesses' sustainability approach is essential due to their considerable impact on the environment and other sustainability dimensions. Air traffic, with its CO_2 and other harmful gas emissions, substantially contributes to climate change, generating air and noise pollution. In this context, airlines are taking measures to mitigate the environmental impact of air traffic by promoting more efficient technologies and biofuels, among other cutting-edge initiatives. The aviation industry has made sustainability its top priority, with airlines providing options to offset emissions and vaulted at raising awareness among passengers about the importance of sustainable travel.

4.1.2 Target population

The survey was administered using social media channels such as Instagram and Facebook. The total sample reached a total of $N = 154$ respondents. Regarding the population target, no specific target for the sample population has been set.

4.1.3 Timing

The survey was administered from Thursday, 11 April 2024, to Sunday, 5 May 2024.

4.1.4 Objective

This survey primarily aims to investigate how respondents perceive and evaluate climate concerns as a whole and the relative environmental impacts stemming from air travel. The following research also intends to test the respondents' knowledge level regarding air travel's climate impact through a quite specific question concerning aviation's global share of energy-related CO_2 emissions. After that, this survey is intended to devise an overall understanding of end-users willingness to pay an additional surcharge to contribute to climate change mitigation, in this case through the purchase of flight tickets supplemented by "green fares"

provided by voluntary carbon offsetting schemes, which programs result presently implemented in many airlines' sustainability strategies. Finally, thanks to the data gathered by the end-question of this survey research and what this work has previously analyzed (*Section 2.6*), it is possible to compare whether the best decarbonization strategies in the aviation industry, according to respondents, correspond to those that are actually deemed to be the most effective according to IATA reports. The first four questions concerning demographic characteristics of respondents will enable categorization of respondents in different sub-groups, permitting to examine how specific demographic characteristics could influence outcomes in the survey-specific questions. This research aspires also to ascertain whether the outcomes resulting from this survey reflect findings of previous studies mentioned in the literature review section (*Section 2.3*) concerning consumers' willingness to pay and beliefs concerning carbon offsetting programs in the aviation industry.
To test the eventual relationship between pairs of variables, chi-squared (χ^2) tests will be performed, utilizing as significance value $\alpha = 0.05$ to determine whether we can reject or not the null hypothesis H_0, to establish the existance of associations between the variables under analysis. The analyses were performed using STATA 18/MP 2 and Microsoft Excel 2016 software.

All the survey questions are listed in the *Appendix A* at the end of this work.

4.2 Results

4.2.1 Summary statistics

Means and standard deviations

Category	***Questions***	***Mean***	***Std. dev.***
Demographic questions	*Q1*	0.6883117	0.4646944
	Q2	2.662338	0.818262
	Q3	3.623377	0.8861898
	Q4	1.74026	0.6241878
Survey-specific questions	*Q5*	3.824675	1.048704
	Q6	1.935065	0.6732549
	Q7	3.032468	1.173893
	Q8	3.668831	0.9838911
	Q9 A.	2.694805	0.9588114
	Q9 B.	2.779221	0.991775
	Q9 C.	2.5	1.150447
	Q10 A.	0.6363636	0.4826152
	Q10 B.	0.2207792	0.4161252
	Q11	2.12987	0.4530405
	Q12	3.779221	1.121663

Table 17: Means and standard deviations for the data gathered from each question in the survey.

4.2.2 Demographic questions

The survey commences by asking respondents to identify themselves according to demographic characteristics, particularly gender, age, education, and income. The survey's respondents' identification step is crucial to enable the sample identification and respondents' classification into relative sub-groups. The obtained sub-groups will then permit the analysis of the eventual relationships between the demographic data and the results obtained from the survey-specific questions concerning climate awareness and sustainability in airlines.

Demographic characteristics of respondents

Characteristics	***Frequency***	***Percent***
Gender ($N = 154$)		
Male	106	68.8%
Female	48	31.2%
Age ($N = 154$)		
Less than 18 years old	2	1.3%
18-25 years old	70	45.5%
26-40 years old	67	43.5%
41-54 years old	11	7.1%
55-65 years old	1	0.6%
65+ years old	3	1.9%
Education ($N = 154$)		
Elementary	0	0%
Secondary	8	5.2%
Post-secondary	76	49.4%
Bachelor's degree	36	23.4%
Master's degree	34	22.1%
PhD degree	0	0%
Income ($N = 154$)		
less than EUR 20,000	53	34.4%
between EUR 20,000 - EUR 50,000	90	58.4%
between EUR 50,000 - EUR 100,000	9	5.8%
more than EUR 100,000	2	1.3%

Table 18: Frequencies of the demographic characteristics of respondents from *Question 1* to *Question 4* of the survey.

Gender *Question 1* of this survey aims to categorize respondents according to their gender. "Male" and "Female" alternatives are provided to respondents.

By analyzing survey results, we can observe that 106 of the 154 respondents were males (68.8%) and 48 females (31.2%). The results are represented below in Figure 19.

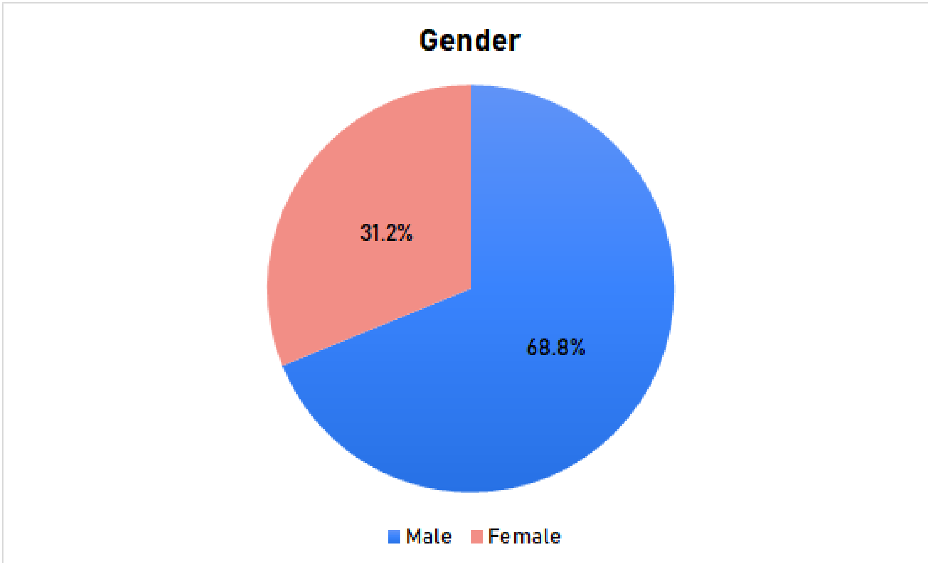

Figure 19: Respondents' classification according to their gender.

Age *Question 2* of this survey asks respondents to collocate themselves in their corresponding age bracket. Most respondents are aged between 18 and 25 years old, representing 45.5% of the total sample (70 respondents). The second most diffuse age group corresponds to respondents aged between 26 and 40 years old, amounting to 67 (43.5%). Further, by observing Figure 20 illustrated below, we can deduce that older respondents constitute a minor part of the survey respondents.

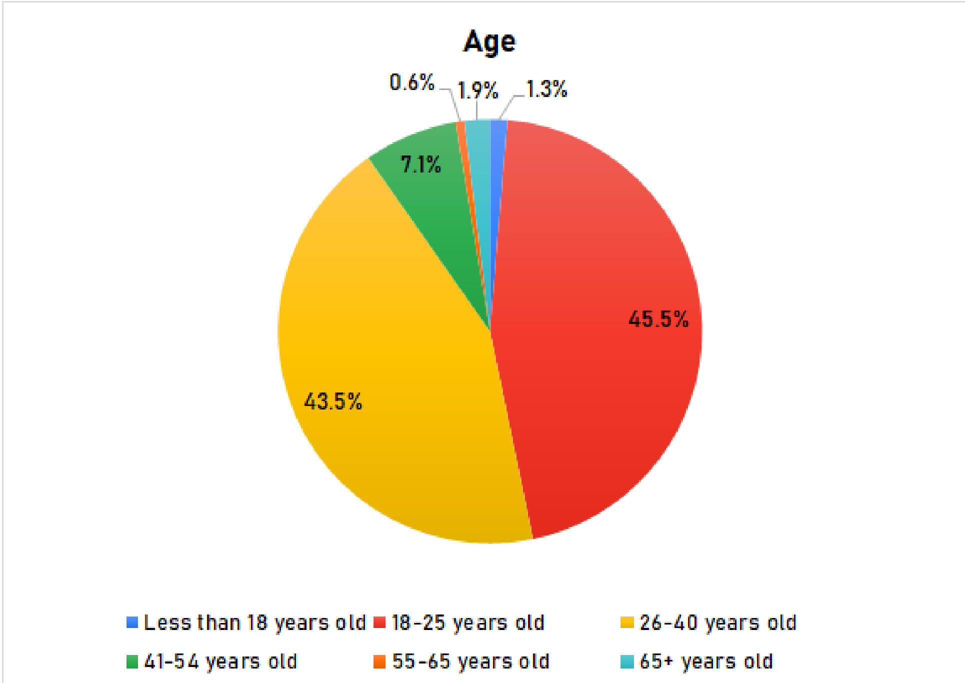

Figure 20: Respondents' classification according to the age bracket to which they belong.

By examining Table 17, we can observe that *Question 2*'s mean exhibits a value of 2.662338, a value in between 2 (where 2 = "18-25 years old") and 3 (where 3 = "26-40 years old"), validating what has been stated earlier. Therefore, on average, respondents are aged between 18 and 40 years old.

Education *Question 3* is intended to categorize respondents according to their education degree. The results highlight that 76 respondents (49.4%) have a post-secondary degree of education, followed by roughly equal shares of respondents with a Bachelor's or Master's degree (23.4% and 22.1%). Results are represented in Figure 21 illustrated below.

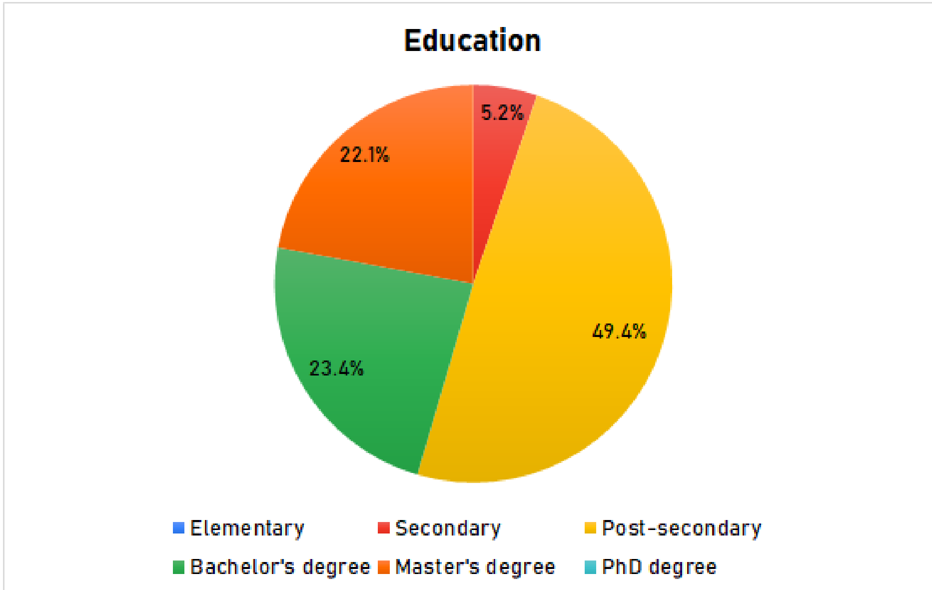

Figure 21: Respondents' classification according to their education degree.

Income The last question targeted at identifying respondents based on their demographic characteristics concerns obtaining a categorization based on respondents' income level. In particular, *Question 4* aims to categorize respondents into different income ranges. The results are visually represented in the below Figure 22, providing a clear and concise overview of the data. By scrutinizing the gathered data, we can notice that 90 respondents have an average income corresponding to a range between EUR 20,000 and EUR 50,000, representing 58.4% of the total sample. The second most diffuse income range proves to be less than EUR 20,000 for 34.4% of the total sample (53 respondents), mainly due to the high frequency of young individuals' participation in the survey as outlined in *Question 2*.

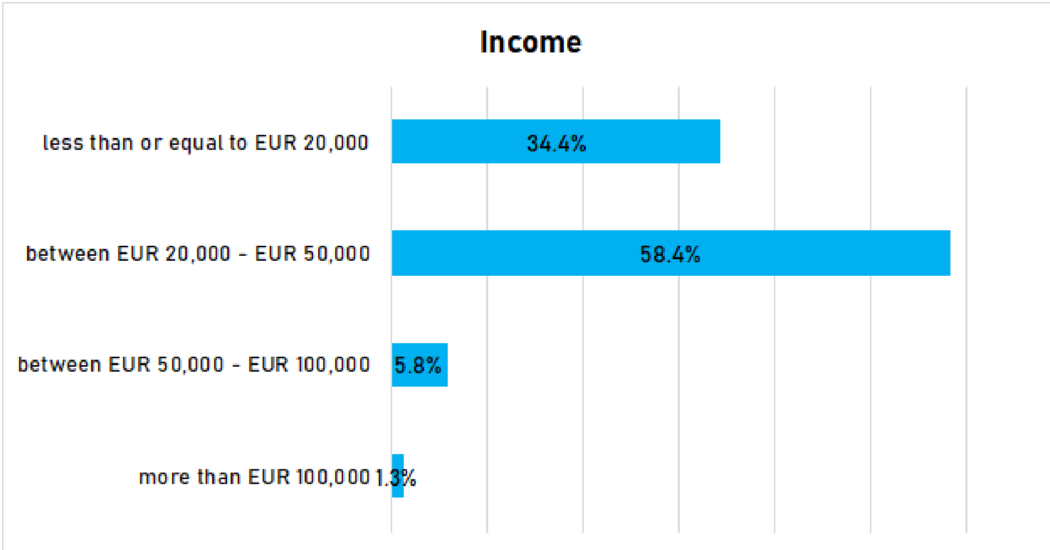

Figure 22: Respondents' classification according to their level of income.

4.2.3 Survey-specific questions

The survey-specific questions represent the core of this research. These questions primarily focus on gathering respondents' data concerning their extent of awareness of the current climate emergency and the relative environmental impacts of air travel, air travel habits, knowledge concerning aviation environmental impact, sustainability preferences, willingness to pay, and personal opinions and beliefs regarding decarbonization strategies. Analogously to demographic questions, some survey-specific questions allow the elaboration of specific subgroups of respondents. In particular, by analyzing answers obtained in *Question 5* about "climate awareness", we can split respondents into groups of "less climate aware" respondents and "fully climate aware" respondents. The same holds for *Question 6* concerning air travel frequency: based on the obtained data, we can break down respondents into different subgroups: respondents who tend to travel more often by air, the ones who tend to travel less, and those who never travel.

Survey-specific questions results

Topic		***Frequency***	***Percent***
Climate awareness ($N = 154$)			
	1 (Not aware)	4	2.6%
	2	11	7.1%
	3	43	27.9%
	4	46	29.9%
	5 (Fully aware)	50	32.5%
Air travel frequency ($N = 154$)			
	Never	36	23.4%
	1-3 times per year	96	62.3%
	4-10 times per year	18	11.7%
	10+ times per year	4	2.6%
Air travel environmental impact awareness ($N = 154$)			
	1 (Not aware)	18	11.7%
	2	31	20.1%
	3	51	33.1%
	4	36	23.4%
	5 (Fully aware)	18	11.7%
Knowledge concerning aviation's environmental impact ($N = 154$)			
	less than 2%	1	0.6%
	around 2%	23	14.9%
	around 7%	33	21.4%
	around 10%	66	42.9%
	around 21%	31	20.1%
Air travel environmental impacts' perception ($N = 154$)			
A. Climate change			
	1 (Not relevant)	16	10.4%
	2	46	29.9%
	3	68	44.2%
	4	17	11.0%
	5 (Very relevant)	7	4.5%
B. Air quality			
	1 (Not relevant)	16	10.4%
	2	42	27.3%
	3	62	40.3%
	4	28	18.2%
	5 (Very relevant)	6	3.9%

Table 19: Part.1: Frequencies of the survey-specific questions' results (from *Question 5* to *Question 9 B.*).

Survey-specific questions results

Topic		***Frequency***	***Percent***
C. Noise pollution			
	1 (Not relevant)	39	25.3%
	2	37	24.0%
	3	45	29.2%
	4	28	18.2%
	5 (Very relevant)	5	3.2%
A. Willingness to pay (low price difference and same airline) ($N = 154$)			
	Ticket 1	98	63.6%
	Ticket 2	56	36.4%
B. Willingness to pay (high price difference and $\neq$ airlines) ($N = 154$)			
	Ticket 1 from Airline company A	34	22.1%
	Ticket 2 from Airline company B	120	77.9%
Beliefs concerning corporate sustainability in airlines ($N = 154$)			
	Not believing in climate emergency and corporate sustainability	7	4.5%
	Aware of climate concerns but not believing in corporate sustainability	120	77.9%
	Aware of climate concerns and believing in corporate sustainability	27	17.5%
Best aviation industry decarbonization strategies ($N = 154$)			
	Mandatory carbon offsetting programs	10	6.5%
	VCO programs	9	5.8%
	Operational enhancements	24	15.6%
	Technological innovation	79	51.3%
	Sustainable Aviation Fuel (SAF)	26	16.9%
	Sustainable cabin practices	6	3.9%

Table 20: Part. 2: Frequencies of the survey-specific questions' results (from *Question 9 C.* to *Question 12*).

Climate awareness The first survey-specific question (*Question 5*) aims to categorize respondents according to their extent of awareness concerning the current climate emergency and its relative environmental concerns. Respondents have been asked to rate their level of environmental consciousness on a scale from 1 (where 1 = "Not aware") to 5 (where 5 = "Fully aware"). This same structure has been revived in *Question 7* for respondents in the more specific context of environmental impacts stemming from air travel. Analogously to *Question 5*, *Question 7* requires respondents to rate their level of awareness on a scale from 1 (not aware) to 5 (fully aware). Results from *Question 5* and *Question 7* are represented in Figure 23 illustrated below.

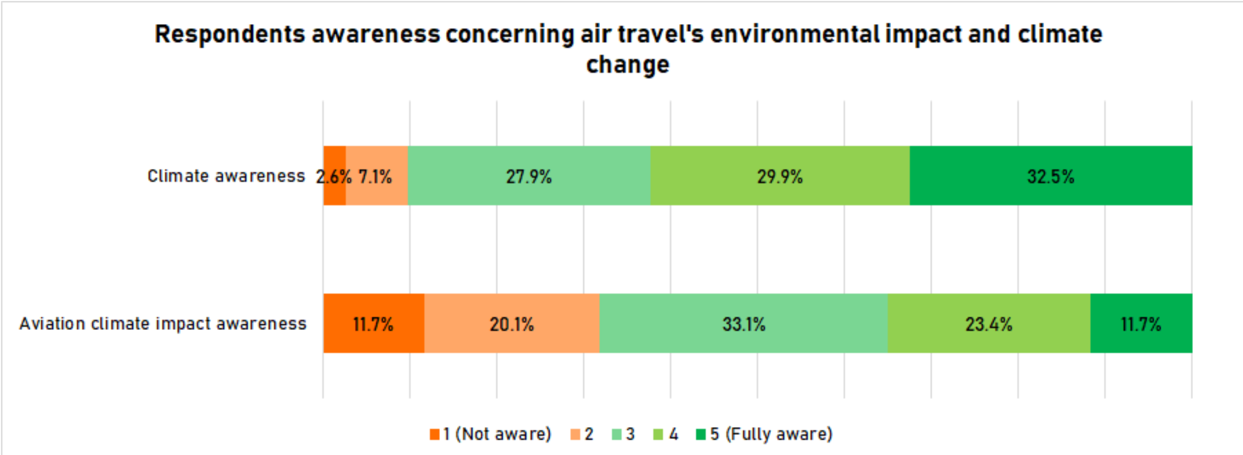

Figure 23: Respondents' level of climate awareness regarding climate emergency and environmental impacts of air travel.

By observing the above Figure 23 and by consulting Table 17, we can deduce that, on average, respondents displayed to be more aware of climate emergency and general climate concerns rather than the specific impact of air travel on the environment. *Question 5*'s responses present a mean of 3.824675, representing roughly a degree 4 of environmental consciousness, while *Question 7*'s data exhibit a mean of 3.032468, representing approximately a degree 3 of awareness. Most of the respondents in Question 5, in fact, declared to be fully aware (degree 5) of general climate concerns, representing 32.5% of the total sample (50 respondents). On the other hand, in Question 7, only 18 respondents (11.7%) claimed to be fully aware of the environmental impacts of air travel.

Air travel frequency *Question 6* is vaulted to categorize respondents based on their air travel habits. In particular, this question aims to gather data concerning the frequency with which respondents utilize airline flight services. Then, as mentioned in *Section 4.2.3*, the collected data will be helpful in further elaborating additional sub-groups of respondents, from those who often travel by air to those who never travel by air at all. The results are represented below in Figure 24.

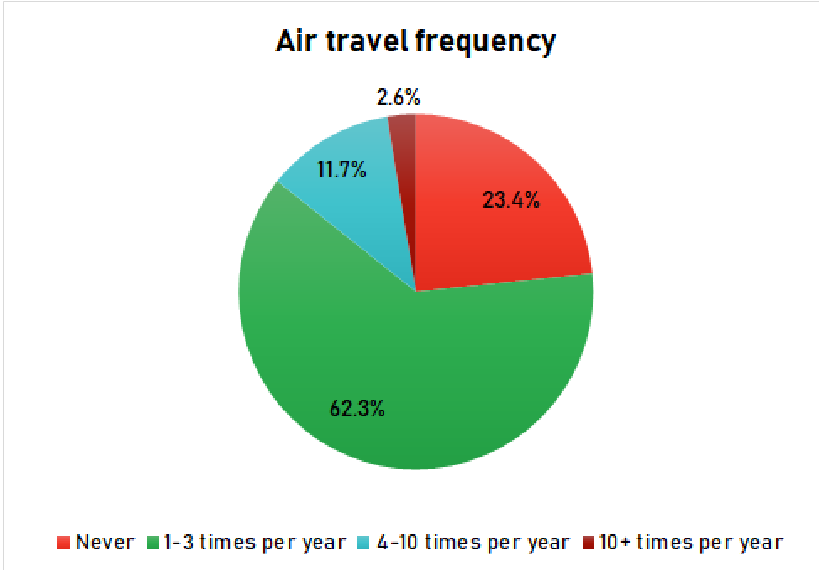

Figure 24: Air travel frequency of respondents.

By examining the above Figure 24 and consulting Table 17, we can conclude that, on average, the most significant part of the respondents tend to travel 1-3 times per year. Question 6's data presents a mean of 1.935065, $\approx$ 2 (where 2 = "1-3 times per year"), confirming what was claimed earlier. 96 respondents (62.3%) claimed to travel by air from 1 to 3 times per year, while only 4 respondents (2.6%) exhibited an air travel frequency of more than 10 times per year.

Respondents' knowledge regarding the aviation climate impact *Question 8* aims to test the respondents' level of knowledge concerning the magnitude of the aviation industry's environmental impact. In particular, this question asks respondents to select, among different alternatives, the global share of energy-related CO_2 emissions for which they believe aviation is accountable. We can then infer whether respondents underestimate or overestimate the aviation industry's environmental impact by examining the results.

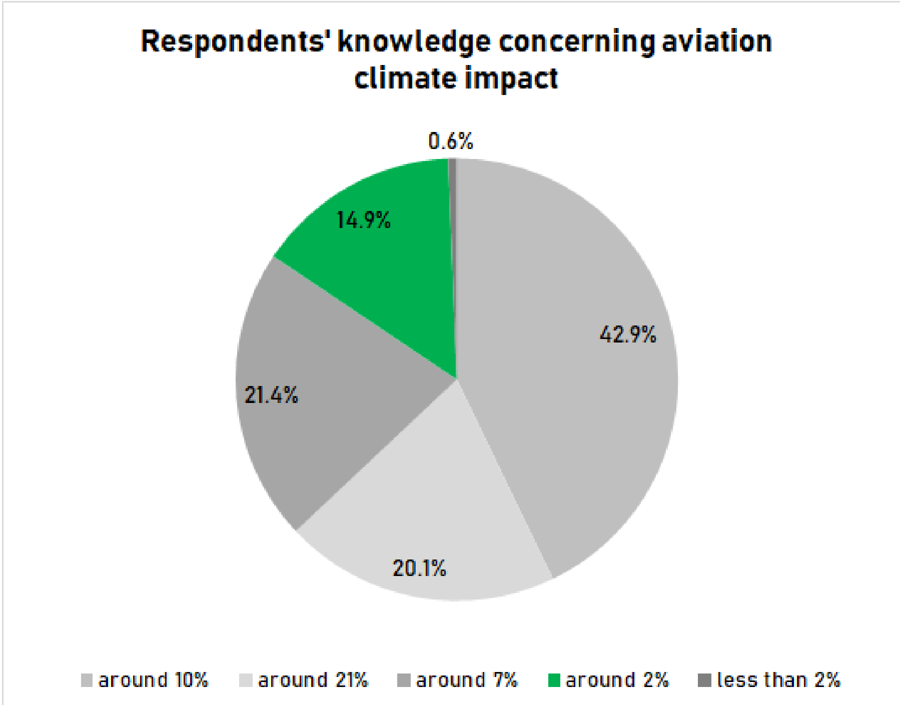

Figure 25: Frequencies of the different amounts of the global share of energy-related CO_2 emissions for which respondents believe the aviation industry is responsible.

By examining Figure 25 and viewing Table 17, we can deduce that, on average, respondents tend to overestimate the aviation industry's responsibility for global energy-related CO_2 emissions. *Question 8*'s mean is equal to $3.668831 \approx 4$, where $4 =$ "around 10%" share. 66 respondents (42.9%) believe that the aviation industry is responsible for around 10% of global energy-related CO_2 emissions, while 33 respondents (21.4%) pick the "around 7%" alternative. However, the correct global share of energy-related CO_2 emissions for which the aviation industry is responsible is around 2%, chosen only by 23 respondents (14.9%), even a lower amount than the exaggerated share of "around 21%", believed to be the correct answer by 31 respondents (20.1%).

Respondents' perception concerning air travel impacts *Question 9* of this survey is articulated in three parts, each dealing with a different specific environmental impact, namely air travel's impact on climate change, air quality, and noise pollution. This question aspires to gather respondents' perceptions of the relevance they attribute to each specific environmental impact, ranging from relevance level 1 (Not relevant) to 5 (Very relevant). Figure 26 below illustrates the relative frequencies recorded for each environmental material impact for the aviation industry.

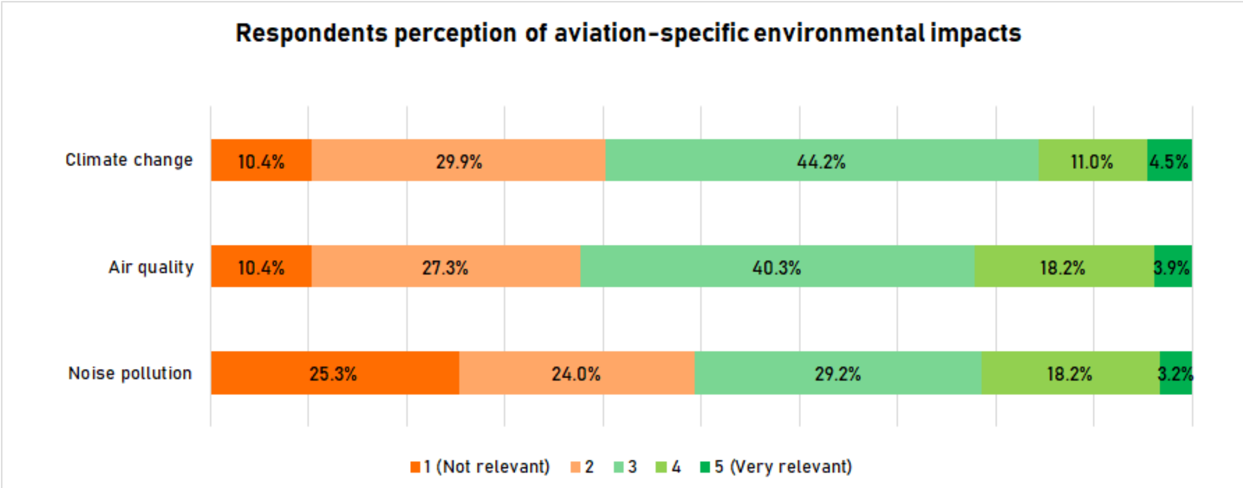

Figure 26: Respondents' level of relevance attributed to each air travel environmental impact.

By consulting Table 17, we can deduce that, on average, respondents tend to attribute more importance to air travel's impact on air quality ($\mu = 2.779221$), followed by the impact on climate change ($\mu = 2.694805$), and noise pollution ($\mu = 2.5$). However, by analyzing Figure 26, we can observe that a significantly lower amount of respondents declared to attribute the highest degree of relevance to all three specific air travel environmental impacts. In particular, 7 respondents (4.5%) claimed to perceive air travel's impact on climate change as "very relevant", 6 respondents (3.9%) in the case of impact on air quality, and 5 respondents (3.2%) in the noise pollution one. Most of the respondents declared a perception of the relevance of degrees 2 and 3.
Furthermore, we can notice straight away how the results concerning the relevance attributed to the air travel impact on noise pollution recorded the highest share of respondents perceiving it as irrelevant (1 = "Not relevant"). In particular, 39 respondents (25.3%) perceive air travel's impact on noise pollution as irrelevant (1 = "Not relevant"). These results may be explained by the remarkable technological progress the aviation industry has made in the last decades, delivering quieter aircraft while respecting the critical Chapter 4 and 14 Noise Standard requirement prescribed by ICAO. As mentioned in *Section 2.3.3*, aircraft's noise production has decreased by 75% in the last three decades thanks to technological advancements (EC, 2024a).

Voluntary Carbon Offsetting: respondents' willingness to pay *Question 10* aims to put respondents in the position to choose between two different price alternatives for their flight tickets: one ticket surcharged by a "green fare" geared towards offsetting carbon emissions and the other without any fee. This question is articulated in two parts: in the first part (Part A), respondents face two flight tickets with a low price difference, proposed by the same airline, whereas, in the second part (Part B), they face two flight tickets presenting a considerable higher price difference, proposed instead by two different airlines. By analyzing the results obtained, we will check whether respondents are willing to spend more to voluntarily offset carbon emissions from their flights, adhering to VCOs offered by airline companies as part of their sustainability strategies, and to what extent.

Part A. Low price difference, same airline The first part of *Question 10* requires respondents to choose which flight ticket to purchase between a ticket surcharged by a ”green fare” prescribed by an airline VCO's scheme (Ticket 1 at EUR 600,00) and one without any surcharge (Ticket 2 at EUR 590,00). The same airline offers the two tickets and presents a low price difference, which equals EUR 10,00. Figure 27 below illustrates the relative frequencies obtained.

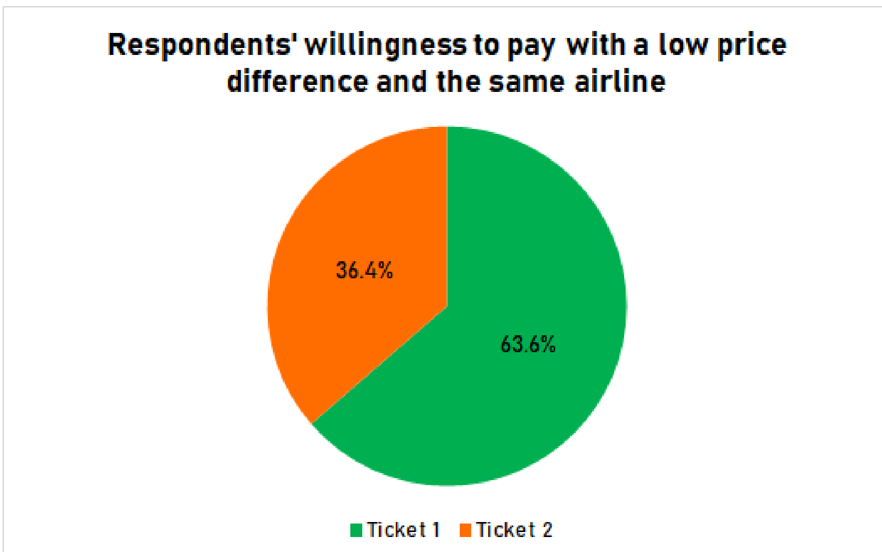

Figure 27: Respondents' willingness to pay when facing a low price difference between a flight ticket surcharged by a ”green fare” (Ticket 1) and one without any fee (Ticket 2).

By observing the above Figure 27, we can deduce that most respondents would voluntarily offset carbon emissions from their flights when facing a low price difference, exhibiting their preference for purchasing Ticket 1. In particular, 98 respondents (63.6%) claimed to be willing to pay a low price difference to adhere to VCOs proposed by airlines.

Part B. High price difference, two different airlines Contrary to the previous case, respondents now face a considerably higher price difference, corresponding to EUR 35.00, as the two airlines offering flight tickets might have different tariffs. The results obtained from this question could also permit an analysis of whether respondents would surrender a considerable amount of their budget to support a more sustainable airline. Figure 28 below illustrates the relative frequencies obtained.

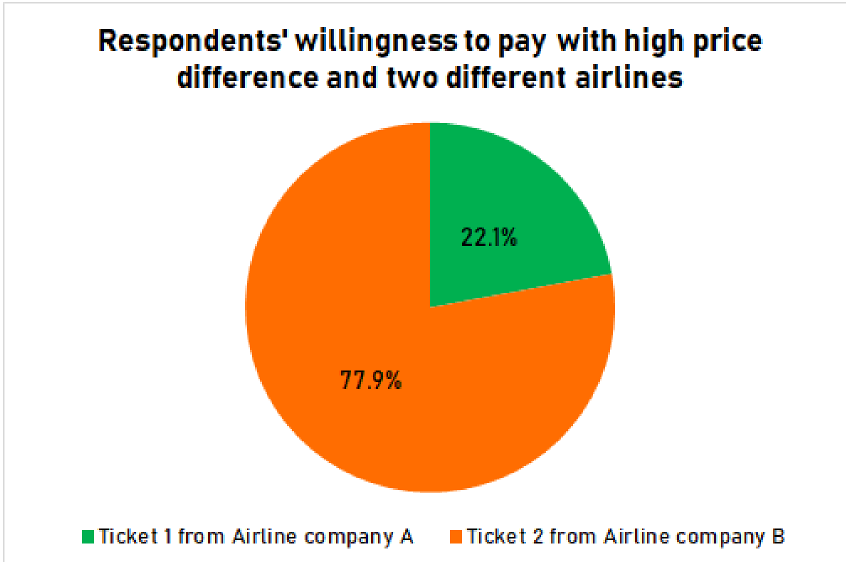

Figure 28: Respondents' willingness to pay when facing a high price difference between a flight ticket surcharged by a "green fare" proposed by an airline adopting VCOs (Ticket 1 from Airline company A) and one without any fee proposed by an airline not implementing VCOs in its sustainability strategy (Ticket 2 from Airline company B).

By observing Figure 28 above, we can notice how a considerable part of respondents are not willing to pay a high price difference to offset carbon emissions from their flights, displaying their preference to proceed with the purchasing of Ticket 2 from the Airline company B. In particular, 120 respondents (77.9%) declared that they would purchase Ticket 2 from Airline company B, consisting of the flight ticket without the "green fare". Only 34 respondents (22.1%) would spend more to offset their emissions, supporting the airline incorporating VCOs in its sustainability strategy.

These results may be explained by the respondents' perception of airlines' corporate sustainability efforts. In particular, as will be analyzed in the next question, most respondents demonstrated that, even if they exhibit a high degree of climate awareness, they still believe that airlines (and companies in general) embrace sustainable practices only for profit, generating greenwashing. This matter is also pointed out at the end of *Section 2.6.3*, where it is mentioned how airlines might choose to implement voluntary carbon offsetting measures in their strategies only to enhance their green reputation, incurring the risk of "greenwashing" their services (Knorr & Eisenkopf, 2020).

Respondents' beliefs concerning environmental concerns and corporate sustainability efforts undertaken by airlines *Question 11* aims to categorize respondents according to their personal sentiments concerning environmental concerns and the sustainability efforts undertaken by airlines. In particular, respondents are provided with three different sentences and must choose the sentence that best reflects their beliefs relative to airlines' corporate sustainability efforts. Figure 29 below illustrates the relative frequencies obtained.

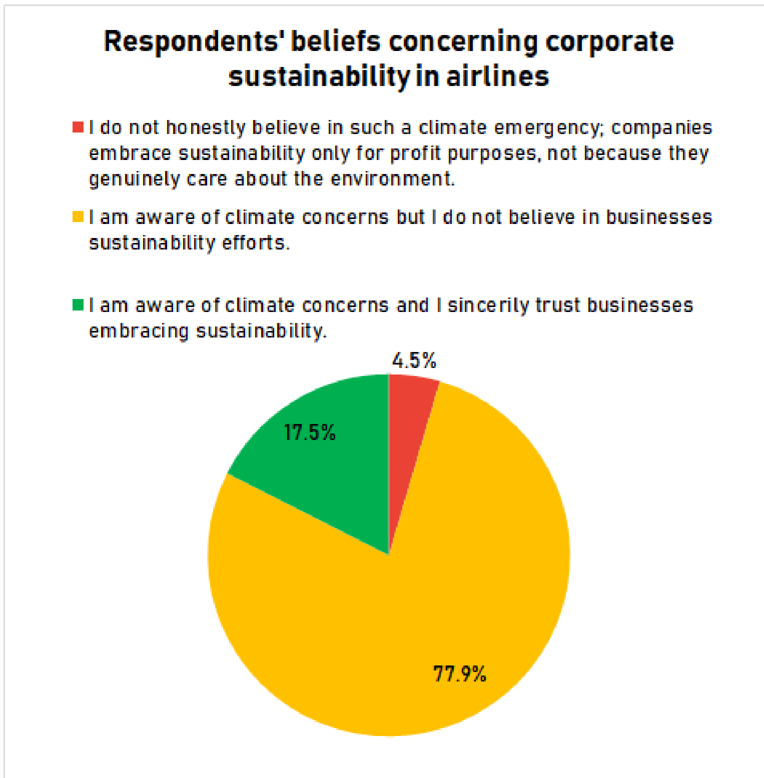

Figure 29: Respondents' beliefs concerning environmental concerns and corporate sustainability efforts undertaken by airlines.

By observing Figure 29 above, we can notice how most of the respondents, even if aware of environmental concerns, do not trust airlines (and companies in general), believing that they embrace sustainability practices in their businesses only for profit, leading to the well-known phenomenon of "greenwashing". In particular, 120 respondents (77.9%) declared to be aware of climate concerns but to not believe in corporate sustainability. These results may also explain, as mentioned before, the findings obtained in Part B of *Question 10*. Only 27 respondents (17.5%) claimed to be aware of climate concerns and to sincerily trust corporate sustainability efforts undertaken by companies.

Best decarbonization strategies in the aviation industry The last question of this survey (*Question 12*) aspires to understand respondents' perceptions regarding the effectiveness of the decarbonization strategies mostly adopted by airlines as part of their decarbonization path to meet the ICAO's net zero goal by 2050 successfully. In particular, this question asks respondents to pick the strategy they believe could be the best at effectively ensuring the attainment of the net zero target. Figure 30 below illustrates the relative frequencies obtained.

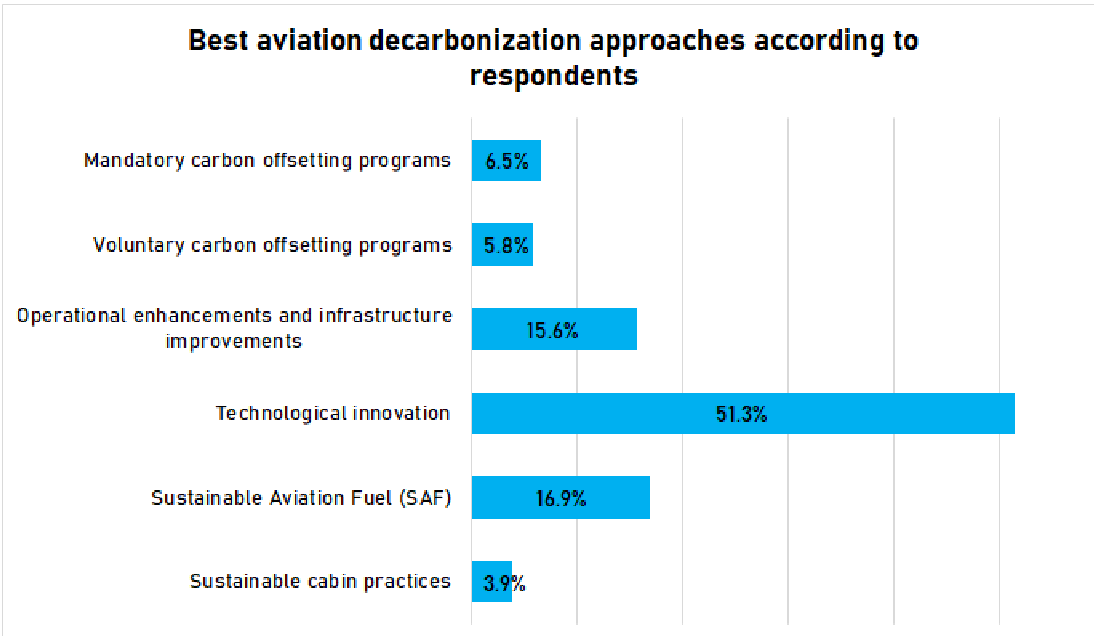

Figure 30: Most effective decarbonization strategies in the aviation industry according to respondents.

By observing the above Figure 30, we can notice that the greatest part of respondents believe that technological innovation could be the best decarbonization strategy to be employed in the aviation industry. 79 respondents (51.3%) pick technological innovation as the best decarbonization strategy, 26 respondents (16.9%) choose the implementation of sustainable aviation fuel (SAF), and 24 respondents (15.6%) pick operational enhancements. In line with what IATA claimed in its reports and to airlines sustainability strategies analyzed in *Section 3*, these results appear to be quite consistent with what effectively are the best decarbonization strategy currently applicable in the aviation industry. However, differently from what most of the respondents believed, technological innovation does not currently consist of the best decarbonization strategy, especially in the short-term, due to the present limited profile of technological progress as far as concerns hybrid and electric aircraft. Instead, the best decarbonization strategy with the highest potential of reducing emissions turns out to

be sustainable aviation fuel (SAF), deemed to be capable of reducing approximately 65% of emissions by IATA.
Secondly, we can compare the results of the carbon offsetting program alternatives. In particular, 10 respondents (6.5%) believe mandatory carbon offsetting programs, such as the EU ETS and the CORSIA scheme, would be the best decarbonization strategies in the aviation industry. In comparison, 9 respondents (5.8%) picked voluntary carbon offsetting programs as the best strategies. In the literature review in *Section 2.3*, we mentioned that several studies affirmed that a noteworthy share of respondents are more inclined to prefer mandatory schemes over voluntary ones (Sonnenschein & Mundaca, 2019)(Sonnenschein & Smedby, 2019). In this case, even if we recorded a relatively small difference, we can observe that 6.5% of the respondents believe mandatory programs are more effective than 5.8% choosing VCOs.

4.2.4 Chi-squared (χ^2) test

Climate awareness and gender The first pair of variables of which we are going to verify the association through the Chi-squared (χ^2) test is "climate awareness" and "gender". Absolute frequencies are visually represented in Figure 31 below.

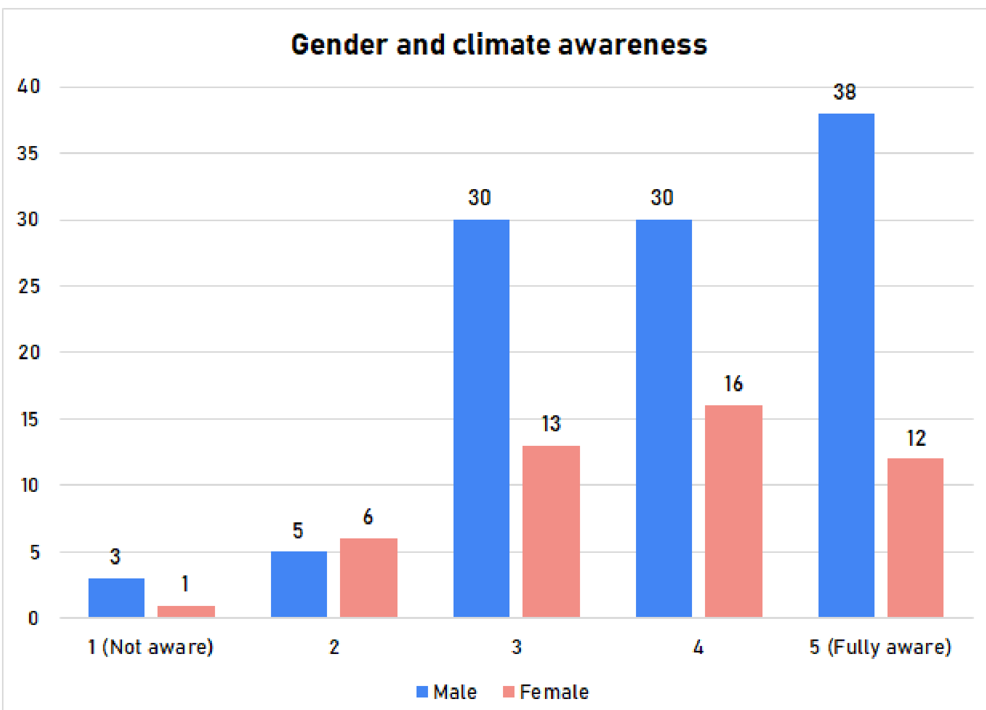

Figure 31: Absolute frequencies of the variables "climate awareness" and "gender".

Then, absolute frequencies and the expected frequencies are represented in the contingency table below (Table 21). The χ^2 test for this pair of variables provides us the result of

$\chi^2(4, N = 154) = 4.3682$, with a p-value = 0.358. As p-value $> \alpha = 0.05$, we fail to reject the null hypothesis H_0, confirming that there is no association between the variables "climate awareness" and "gender".

Gender	*Climate awareness*					**Total**
	1 (Not aware)	**2**	**3**	**4**	**5 (Fully aware)**	
Female	1	6	13	16	12	48
	(1.2)	(3.4)	(13.4)	(14.3)	(15.6)	(48.0)
Male	3	5	30	30	38	106
	(2.8)	(7.6)	(29.6)	(31.7)	(34.4)	(106.0)
Total	4	11	43	46	50	154
	(4.0)	(11.0)	(43.0)	(46.0)	(50.0)	(154.0)

Absolute frequencies and (expected frequencies)

Table 21: Contingency table of the variables "climate awareness" and "gender".

Climate awareness and age The next couple of variables we want to test are "climate awareness" and "age" variables. Absolute frequencies are graphically illustrated below in Figure 32.

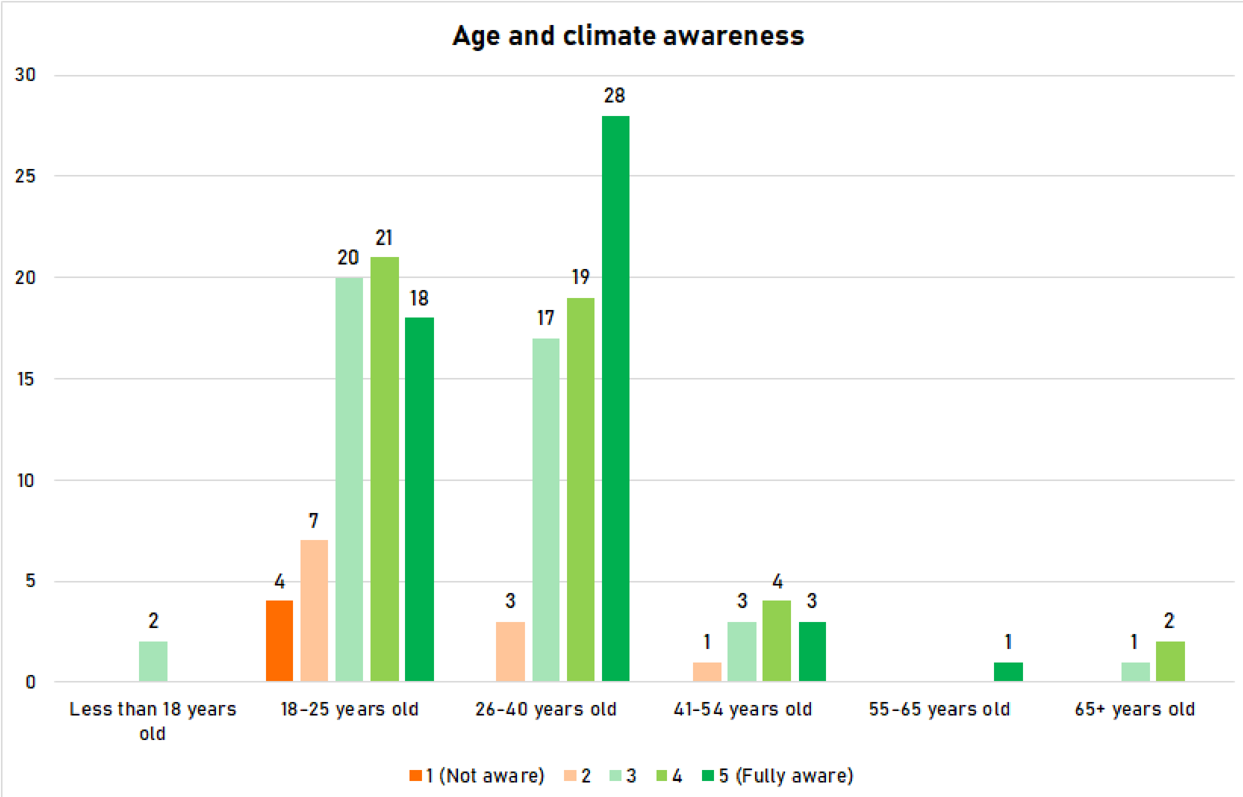

Figure 32: Absolute frequencies of the variables "climate awareness" and "age".

The contingency table representing absolute frequency and the relative expected frequencies necessary to perform the chi-squared (χ^2) test is represented in Table 32.
Accordingly, the chi-squared test provides us a value of $\chi^2(20, N = 154) = 19.3129$. Consequently, p-value$= 0.502 > \alpha = 0.05$, leading to the acceptance of the null hypothesis H_0, stating the absence of association between variables.

This result demonstrates that respondents tend to be climate aware regardless of age, despite some studies claiming that younger individuals tend to be more climate aware than older ones.

Age	*Climate awareness*					**Total**
	1 (Not aware)	**2**	**3**	**4**	**5 (Fully aware)**	
Less than	0	0	2	0	0	2
18 years old	(0.1)	(0.1)	(0.6)	(0.6)	(0.6)	(2.0)
18-25	4	7	20	21	18	70
years old	(1.8)	(5.0)	(19.5)	(20.9)	(22.7)	(70.0)
26-40	0	3	17	19	28	67
years old	(1.7)	(4.8)	(18.7)	(20.0)	(21.8)	(67.0)
41-54	0	1	3	4	3	11
years old	(0.3)	(0.8)	(3.1)	(3.3)	(3.6)	(11.0)
55-65	0	0	0	0	1	1
years old	(0.0)	(0.1)	(0.3)	(0.3)	(0.3)	(1.0)
65+	0	0	1	2	0	3
years old	(0.1)	(0.2)	(0.8)	(0.9)	(1.0)	(3.0)
Total	4	11	43	46	50	154
	(4.0)	(11.0)	(43.0)	(46.0)	(50.0)	(154.0)

Absolute frequencies and (expected frequencies)

Table 22: Contingency table of the variables "climate awareness" and "age".

Climate awareness and education Another couple of variables worth testing are the "climate awareness" and "education" variables. Figure 33 below pictures a visual representation of absolute frequencies.

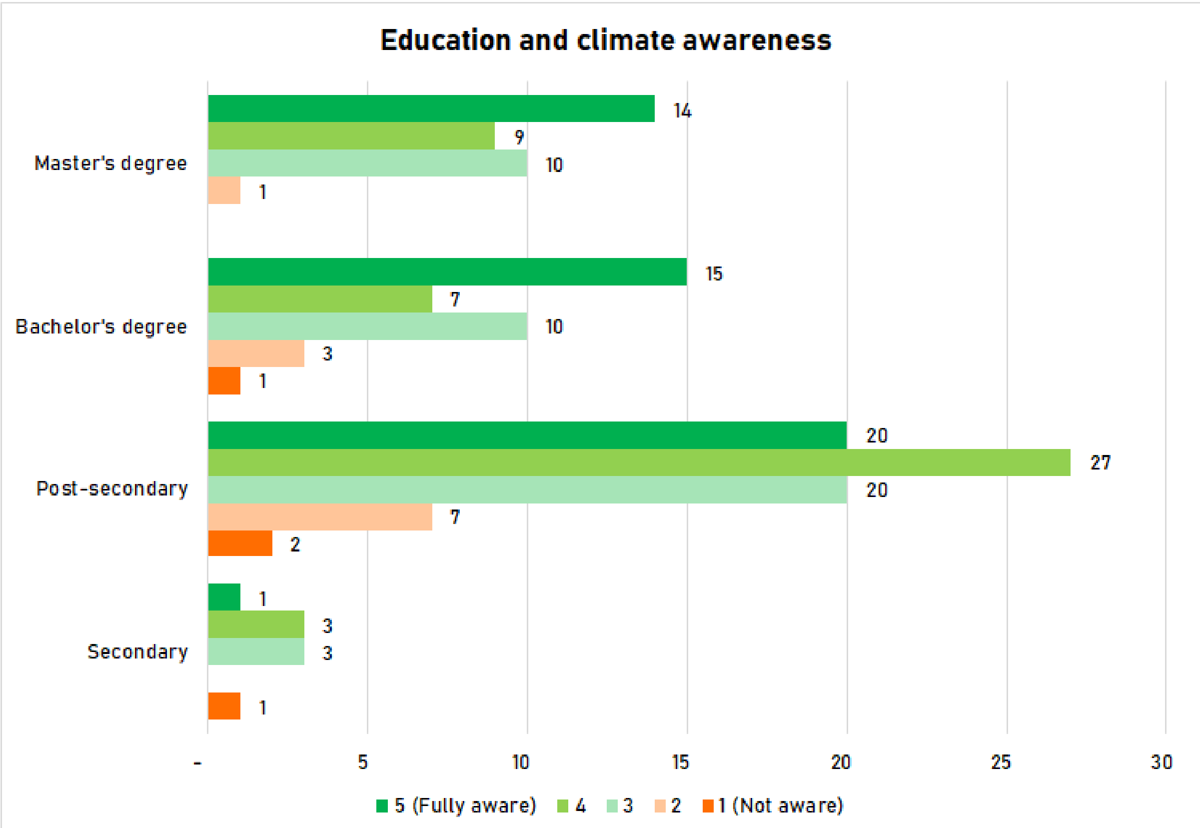

Figure 33: Absolute frequencies of the variables "climate awareness" and "education".

Table 23 represents the absolute and expected frequencies for the pair of variables under analysis. Then, the chi-squared test results to be $\chi^2(12, N = 154) = 12.2190$, having a p-value equal to 0.428. Since $0.428 > \alpha = 0.05$, we fail to reject H_0, confirming no association between variables.

This outcome leads us to conclude that even respondents with a lower education degree recognize climate concerns. By analyzing Figure 33, in fact, we can notice that respondents with a post-secondary degree exhibit a notable frequency at a high degree of climate awareness. However, literature findings concerning studies on the relationship between climate awareness and education affirmed that individuals with a higher degree of education tend to be more climate aware (see *Section 2.3*).

Education	*Climate awareness*					**Total**
	1 (Not aware)	**2**	**3**	**4**	**5 (Fully aware)**	
Secondary	1	0	3	3	1	8
	(0.2)	(0.6)	(2.2)	(2.4)	(2.6)	(8.0)
Post-secondary	2	7	20	27	20	76
	(2.0)	(5.4)	(21.2)	(22.7)	(24.7)	(76.0)
Bachelor's	1	3	10	7	15	36
Degree	(0.9)	(2.6)	(10.1)	(10.8)	(11.7)	(36.0)
Master's	0	1	10	9	14	34
Degree	(0.9)	(2.4)	(9.5)	(10.2)	(11.0)	(34.0)
Total	4	11	43	46	50	154
	(4.0)	(11.0)	(43.0)	(46.0)	(50.0)	(154.0)

Absolute frequencies and (expected frequencies)

Table 23: Contingency table of the variables "climate awareness" and "education".

Climate awareness and air travel environmental impact awareness The next couple of variables to be analyzed are "climate awareness" and "air travel environmental impact awareness." This analysis aims to understand whether climate-aware individuals exhibit their awareness accordingly for the specific environmental impact produced by the commercial aviation industry. Figure 34 graphically represents the absolute frequencies for the variables under analysis.

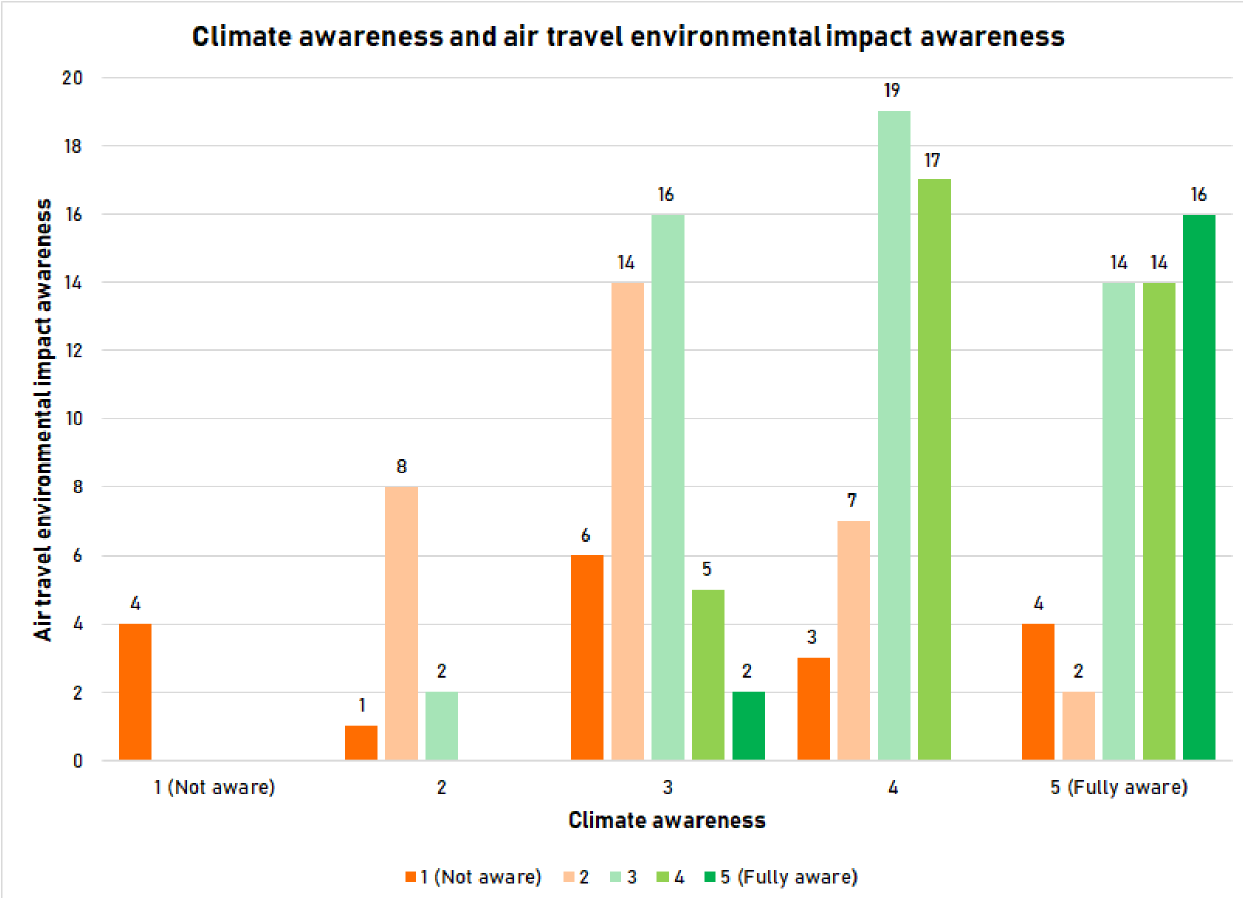

Figure 34: Absolute frequencies of the variables "climate awareness" and "air travel environmental impact awareness".

The contingency table for "climate awareness" and "air travel environmental impact awareness" variables is represented below by Table 24. The chi-squared value for this pair of variables is equal to $\chi^2(16, N = 154) = 95.1519$, with a p-value $= 0.000$. From this outcome, we can immediately notice that the p-value obtained is lower than the significance value $\alpha = 0.05$, leading to the rejection of the null hypothesis H_0 and thus confirming an association between the variables analyzed.

Then, respondents who exhibit some degree of climate awareness are also aware, of the environmental impacts caused by air travel.

Climate awareness	*Air travel environmental impact awareness*					**Total**
	1 (Not aware)	**2**	**3**	**4**	**5 (Fully aware)**	
1 (Not aware)	4 (0.2)	0 (0.6)	0 (2.2)	0 (2.4)	0 (2.6)	4 (4.0)
2	1 (1.3)	8 (2.2)	2 (3.6)	0 (2.6)	0 (1.3)	11 (11.0)
3	6 (5.0)	14 (8.7)	16 (14.2)	5 (10.1)	2 (5.0)	43 (43.0)
4	3 (5.4)	7 (9.3)	19 (15.2)	17 (10.8)	0 (5.4)	46 (46.0)
5 (Fully aware)	4 (5.8)	2 (10.1)	14 (16.6)	14 (11.7)	16 (5.8)	50 (50.0)
Total	18 (18.0)	31 (31.0)	51 (51.0)	36 (36.0)	18 (18.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 24: Contingency table of the variables "climate awareness" and "air travel environmental impact awareness".

Air travel frequency and air travel environmental impact awareness The following two variables that are going to be tested are "air travel environmental impact awareness" and "air travel frequency", for which absolute frequencies are illustrated in Figure 35.

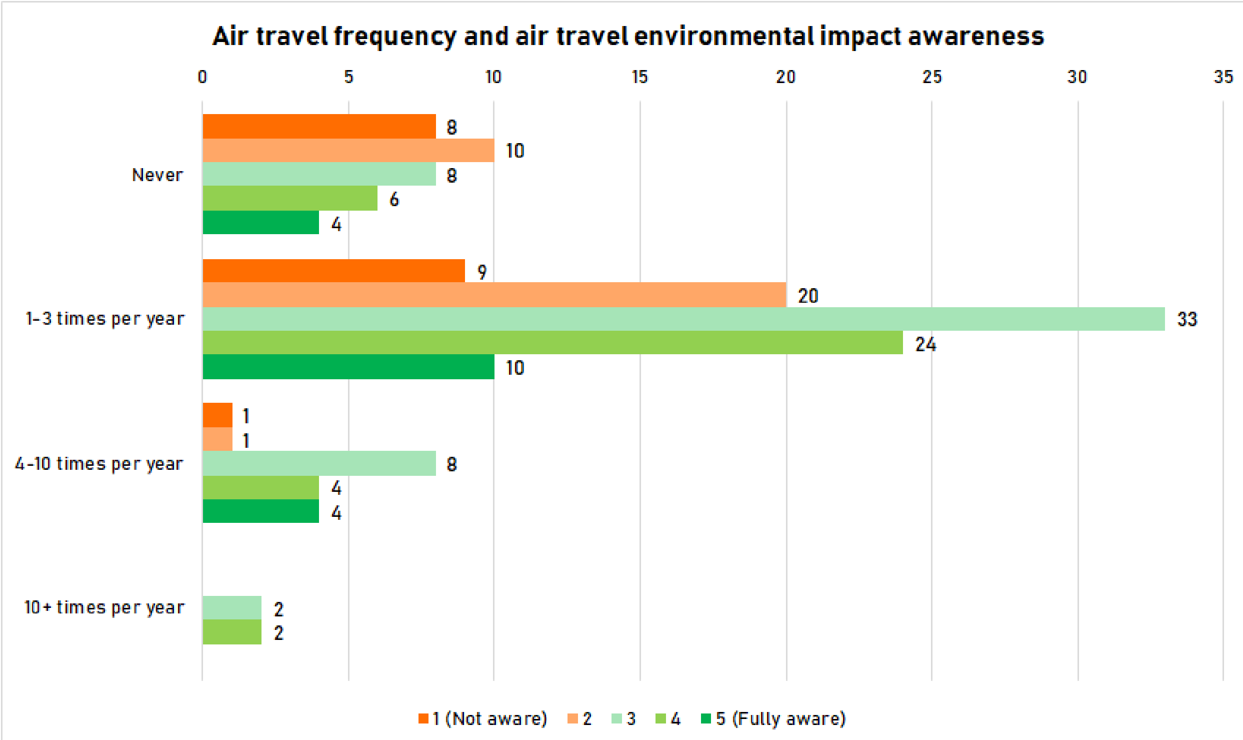

Figure 35: Absolute frequencies of the variables "air travel environmental impact awareness" and "air travel frequency".

Absolute and expected frequencies of the variables under analysis are represented by Table 25 below. The chi-squared test provide us the result of $\chi^2(12, N = 154) = 15.4001$, with the p-value = 0.220. As $0.220 > \alpha = 0.05$, we fail to reject the null hypothesis H_0, concluding that there is no association between the two variables.

Therefore, there is no association between the frequency by which respondents travel by air and their degree of awareness regarding the environmental impact of aircraft.

Air travel frequency	*Air travel environmental impact awareness*					**Total**
	1 (Not aware)	**2**	**3**	**4**	**5 (Fully aware)**	
Never	8 (4.2)	10 (7.2)	8 (11.9)	6 (8.4)	4 (4.2)	36 (36.0)
1-3 times per year	9 (11.2)	20 (19.3)	33 (31.8)	24 (22.4)	10 (11.2)	96 (96.0)
4-10 times per year	1 (2.1)	1 (3.6)	8 (6.0)	4 (4.2)	4 (2.1)	18 (18.0)
10+ times per year	0 (0.5)	0 (0.8)	2 (1.3)	2 (0.9)	0 (0.5)	4 (4.0)
Total	18 (18.0)	31 (31.0)	51 (51.0)	36 (36.0)	18 (18.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 25: Contingency table of the variables "air travel environmental impact awareness" and "air travel frequency".

Income and willingness to pay (low price difference) The following two variables to be analyzed are "income" and "willingness to pay (low price difference)". This test examines whether the respondents' income level affects their willingness to pay for voluntary carbon offsetting at a low price difference. Figure 36 graphically illustrates the absolute frequencies for the variables under analysis.

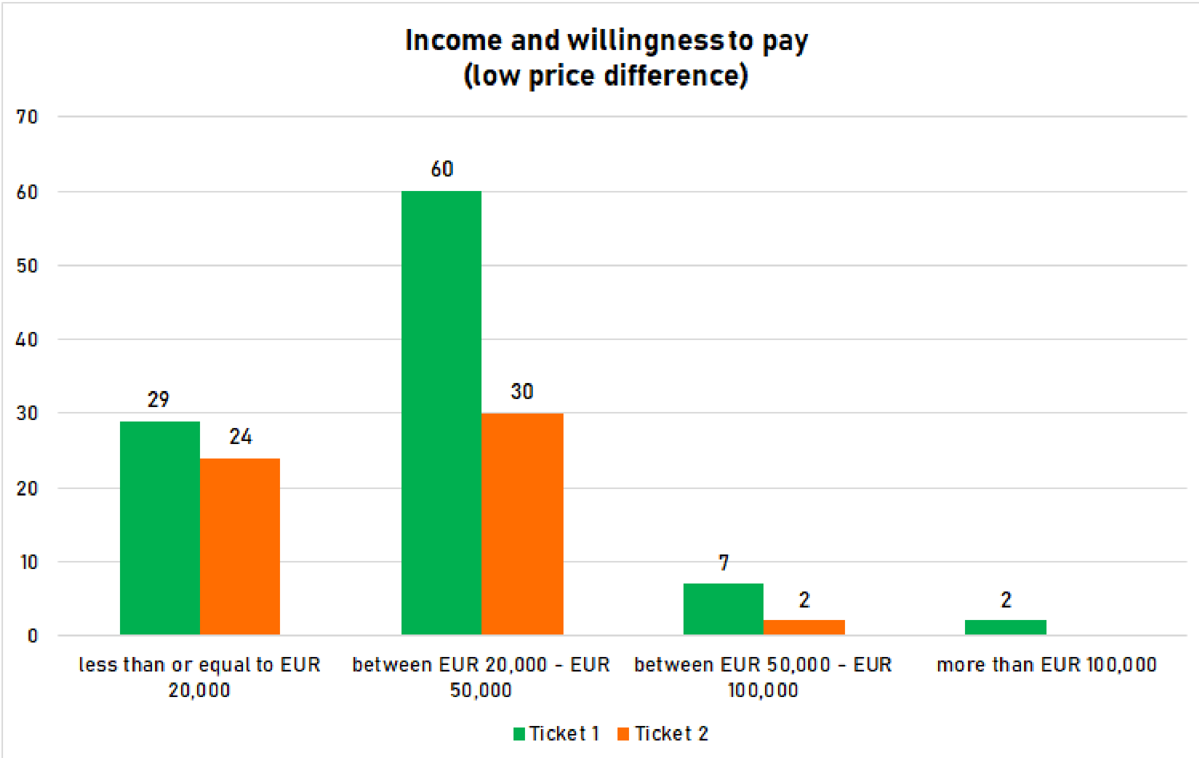

Figure 36: Absolute frequencies of the variables "income" and "willingness to pay (low price difference)".

Table 26 illustrates the absolute and expected frequencies of the interested variables. The chi-squared value for this test results to be equal to $\chi^2(3, N = 154) = 4.0999$, with a p-value equal to 0.251. As $0.251 > \alpha = 0.05$, we fail to reject H_0, confirming that there is no association between variables.

Hence, for a very low price difference, respondents are willing to pay for voluntary carbon offsettings regardless of their income level.

Income	*Willingness to pay (low price difference)*		**Total**
	Ticket 2	**Ticket 1**	
less than EUR 20,000	24 (19.3)	29 (33.7)	53 (53.0)
EUR 20,000 - EUR 50,000	30 (32.7)	60 (57.3)	90 (90.0)
EUR 50,000 - EUR 100,000	2 (3.3)	7 (5.7)	9 (9.0)
EUR 100,000 +	0 (0.7)	2 (1.3)	2 (2.0)
Total	56 (56.0)	98 (98.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 26: Contingency table of the variables "income" and "willingness to pay (low price difference)".

Income and willingness to pay (high price difference, different airlines) The following two variables under analysis are "income" and "willingness to pay (high price difference, different airlines)". This test examines whether the respondents' income level influences their decision to pay for voluntary carbon offsetting at a considerable price difference involving two airlines. Figure 37 represents the absolute frequencies for the variables under analysis.

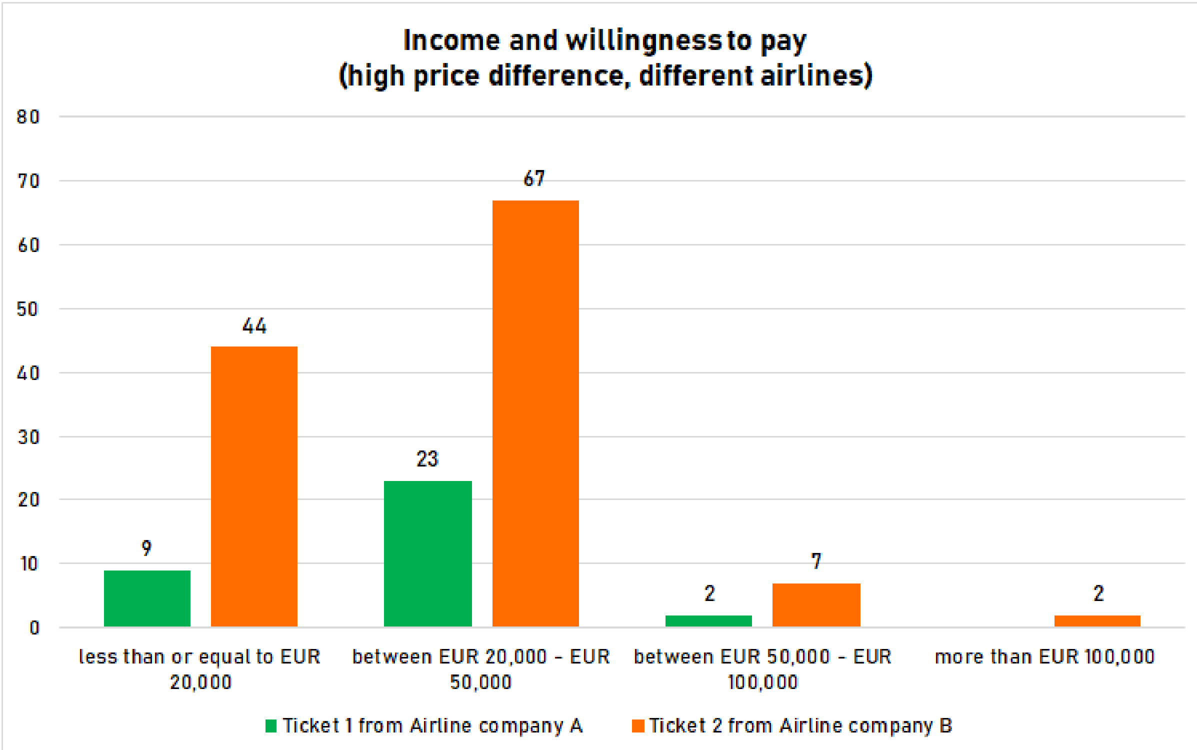

Figure 37: Absolute frequencies of the variables "income" and "willingness to pay (high price difference, different airlines)".

Then, Table 27 represents the contingency table of the variables analyzed. The chi-squared test for these two variables shows us the result of $\chi^2(3, N = 154) = 1.9998$, with a p-value = 0.572, visually higher than the significance level $\alpha = 0.05$. Therefore, we fail to reject H_0, concluding that there is no association between respondents' income level and their decision to pay a high price difference to voluntary carbon offset their flights.

Income	*Willingness to pay (high price difference, different airlines)*		**Total**
	Ticket 2 from Airline company B	**Ticket 1 from Airline company A**	
less than EUR 20,000	44 (41.3)	9 (11.7)	53 (53.0)
EUR 20,000 - EUR 50,000	67 (70.1)	23 (19.9)	90 (90.0)
EUR 50,000 - EUR 100,000	7 (7.0)	2 (2.0)	9 (9.0)
EUR 100,000 +	2 (1.6)	0 (0.4)	2 (2.0)
Total	120 (120.0)	34 (34.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 27: Contingency table of the variables "income" and "willingness to pay (high price difference, different airlines)".

Gender and willingness to pay (low price difference) With the following analysis we want to test the association between the variables "gender" and "willingness to pay (low price difference)". Figure 38 graphically represents the variables under analysis.

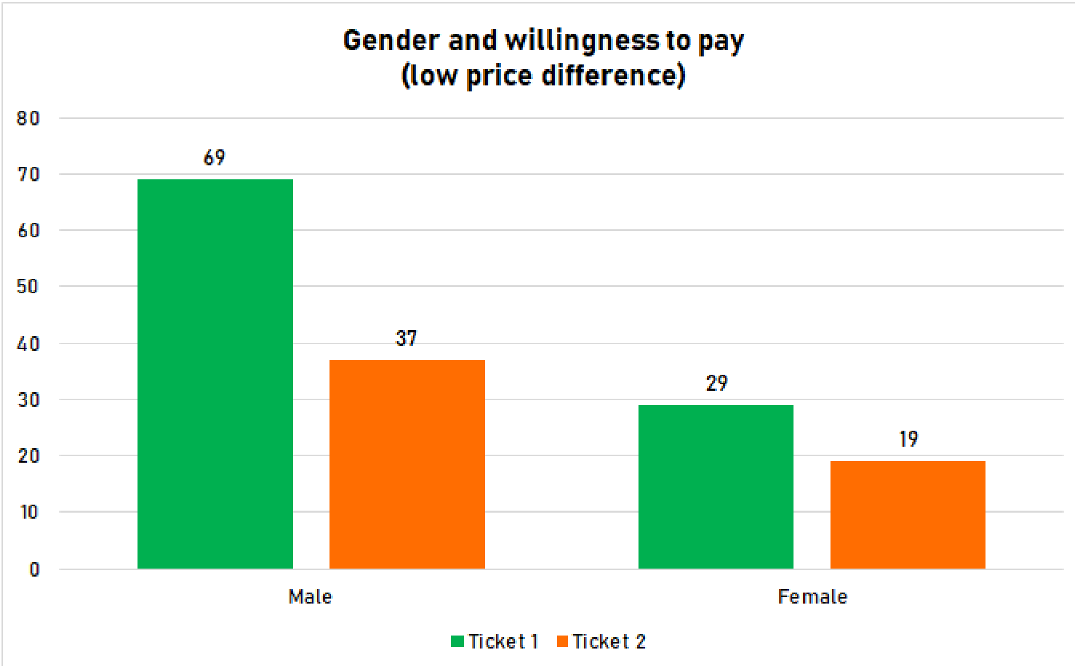

Figure 38: Absolute frequencies of the variables "gender" and "willingness to pay (low price difference)".

The contingency table for the variables "gender" and "willingness to pay (low price difference)" is represented in the table below (Table 28). The chi-squared value for this pair of variables results equal to $\chi^2(1, N = 154) = 0.3124$, with a p-value equal to 0.576. As $0.576 > \alpha = 0.05$, we fail to reject the null hypothesis H_0, leading us to the conclusion of the absence of association between variables.

Hence, the respondents' gender does not affect their decision to pay a lower price difference to offset their emissions when buying flight tickets.

Gender	*Willingness to pay (low price difference)*		**Total**
	Ticket 2	**Ticket 1**	
Female	19 (17.5)	29 (30.5)	48 (48.0)
Male	37 (38.5)	69 (67.5)	106 (106.0)
Total	56 (56.0)	98 (98.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 28: Contingency table of the variables "gender" and "willingness to pay (low price difference)".

Income and willingness to pay (high price difference, different airlines) The following pair of variables analyzed by chi-squared test are "gender" and "willingness to pay (high price difference, different airlines)". Figure 39 illustrates the absolute frequencies for the above mentioned variables.

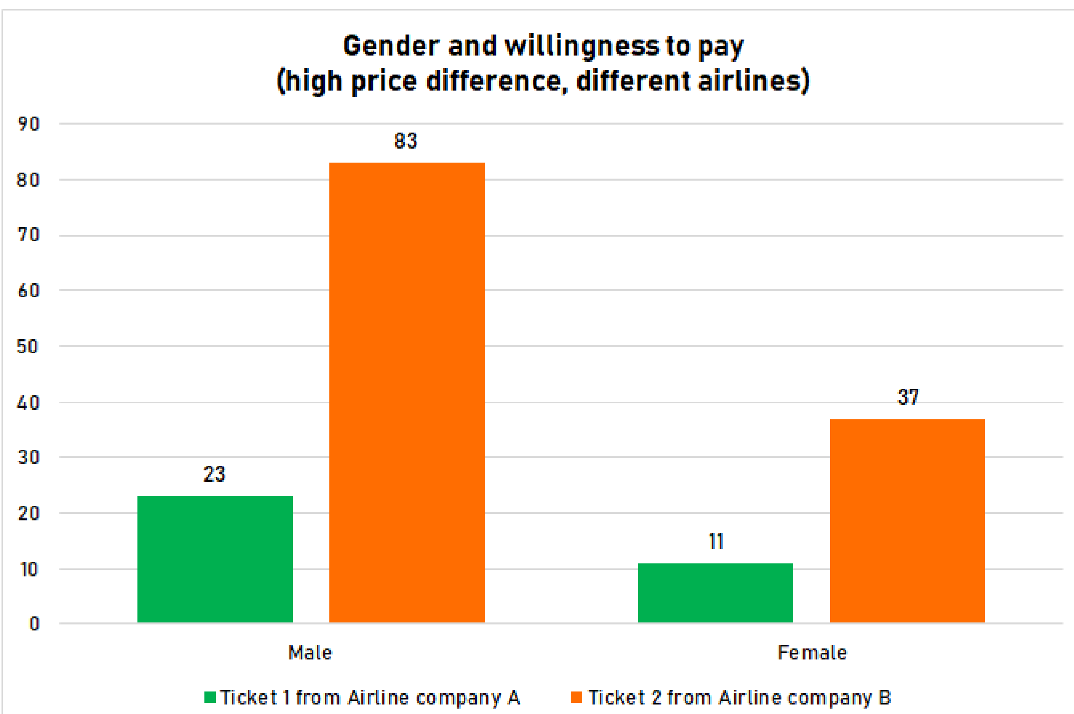

Figure 39: Absolute frequencies of the variables "gender" and "willingness to pay (high price difference, different airlines)".

Then, the contingency table illustrating absolute and expected frequencies for the variables concerned is represented below (Table 28). The chi-squared test for this pair of variables gives us the result of $\chi^2(1, N = 154) = 0.0285$, with a p-value visually higher than the significance level $\alpha = 0.05$ equal to 0.866, leading us to the acceptance of H_0. As a result, the variables do not exhibit any association.

As a consequence, respondents' decision to spend or not a considerable price difference to offset carbon emissions from their flights does not depend on their gender.

Gender	*Willingness to pay (high price difference, different airlines)*		**Total**
	Ticket 2 from Airline company A	**Ticket 1 from Airline company B**	
Female	37 (37.4)	11 (10.6)	48 (48.0)
Male	83 (82.6)	23 (23.4)	106 (106.0)
Total	120 (120.0)	34 (34.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 29: Contingency table of the variables "gender" and "willingness to pay (high price difference, different airlines)".

Age and willingness to pay (low price difference) The following pair of variables under analysis are "age" and "willingness to pay (low price difference)". Figure 40 depicts the absolute frequencies for the variables concerned.

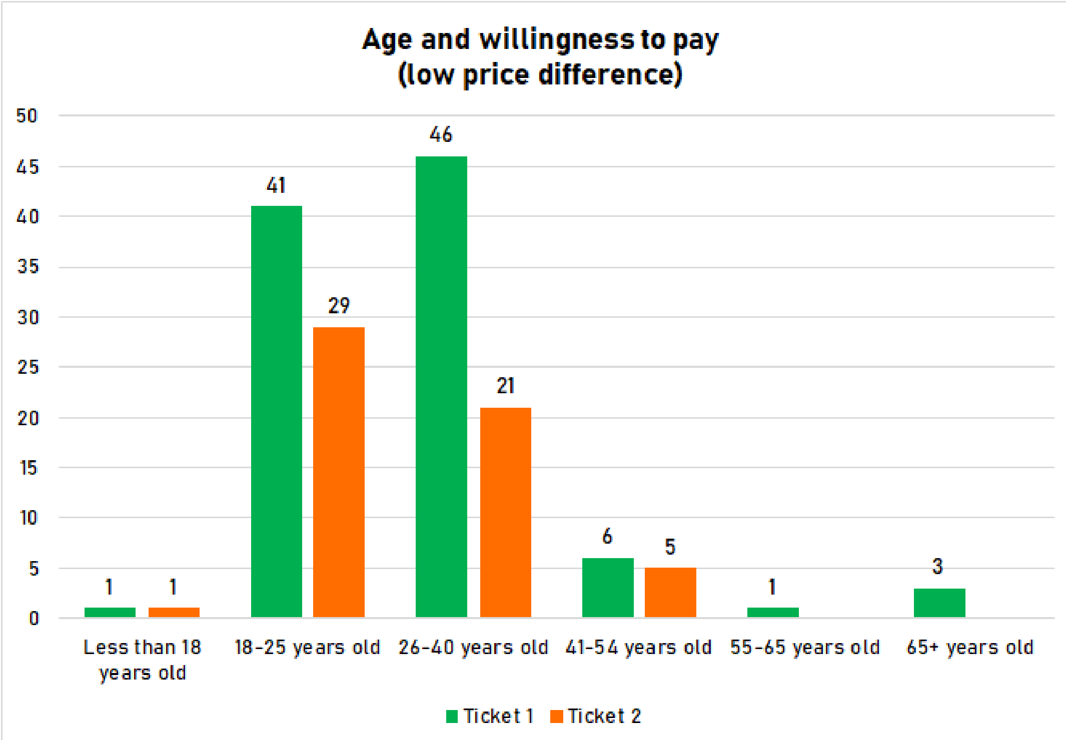

Figure 40: Absolute frequencies of the variables "age" and "willingness to pay (low price difference)".

Table 30 below represents the contingency table for the variables "age" and "willingness to pay (low price difference)". The chi-squared value obtained from the test is equal to $\chi^2(5, N = 154) = 4.3451$, with a p-value = 0.501. Since $0.501 > \alpha = 0.05$, we fail to reject the null hypothesis H_0, concluding that there is no association between the variables under analysis.

Therefore, it is clear from our chi-squared test's result that respondents' age is not associated with their decision to pay a low price difference to offset carbon emissions from their flights when buying tickets. This conclusion is backed by the observation of Figure 40, which shows that both younger and older respondents voluntarily choose to offset carbon emissions from their flights when the VCO involves a low price difference.

Age	*Willingness to pay (low price difference)*		**Total**
	Ticket 2	**Ticket 1**	
Less than 18 years old	1 (0.7)	1 (1.3)	2 (2.0)
18-25 years old	29 (25.5)	41 (44.5)	70 (70.0)
26-40 years old	21 (24.4)	46 (42.6)	67 (67.0)
41-54 years old	5 (4.0)	6 (7.0)	11 (11.0)
55-65 years old	0 (0.4)	1 (0.6)	1 (1.0)
65+ years old	0 (1.1)	3 (1.9)	3 (3.0)
Total	56 (56.0)	98 (98.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 30: Contingency table of the variables ”age” and ”willingness to pay (low price difference)”.

Age and willingness to pay (high price difference, different airlines) The next couple of variables to be analyzed are ”age” and ”willingness to pay (high price difference, different airlines)”. Figure 41 below pictures the absolute frequencies of the abovementioned variables.

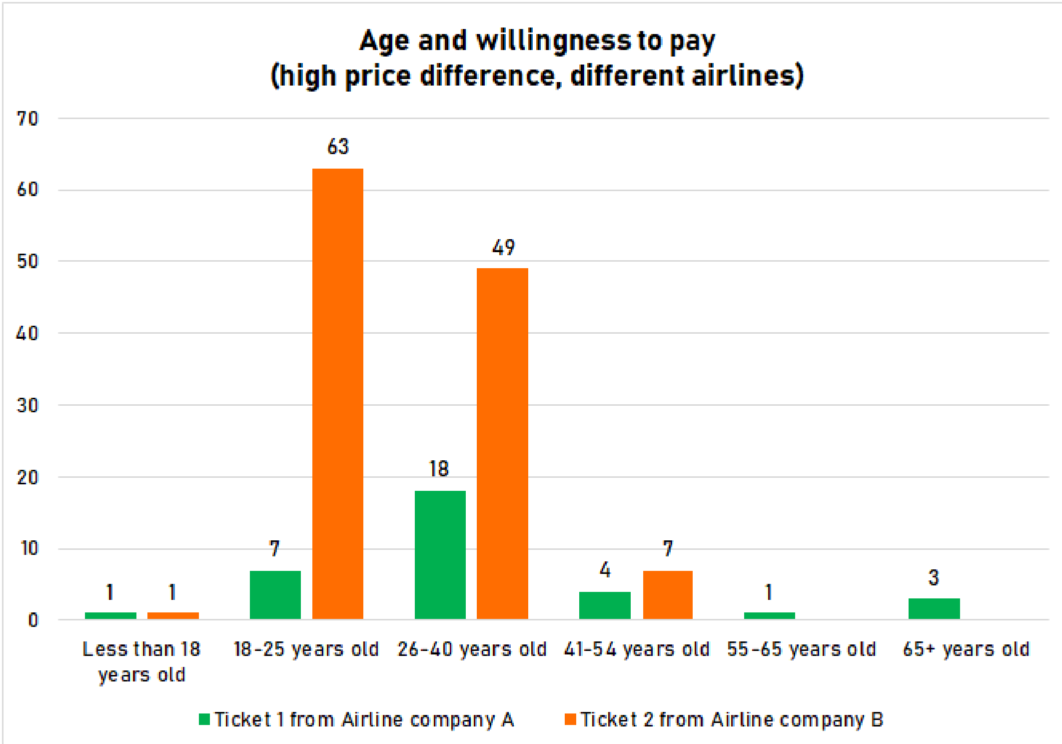

Figure 41: Absolute frequencies of the variables "age" and "willingness to pay (high price difference, different airlines)".

Then, the following Table 31 represents the contingency table of the variables "age" and "willingness to pay (high price difference, different airlines)". The chi-squared test for this pair of variables gives us the result of $\chi^2(5, N = 154) = 23.1572$, with a p-value $= 0.000$. As p-value $< \alpha = 0.05$, we can reject the null hypothesis H_0, confirming that there is an association between variables.

In this case, by examining Figure 41, most young individuals choose not to pay more for their flight tickets to offset their emissions. Therefore, according to these results, younger individuals are more reluctant to pay a considerably higher price difference for voluntary carbon offsettings than older individuals.

Age	*Willingness to pay (high price difference, different airlines)*		Total
	Ticket 2 from Airline company B	**Ticket 1 from Airline company A**	
Less than 18 years old	1 (1.6)	1 (0.4)	2 (2.0)
18-25 years old	63 (54.5)	7 (15.5)	70 (70.0)
26-40 years old	49 (52.2)	18 (14.8)	67 (67.0)
41-54 years old	7 (8.6)	4 (2.4)	11 (11.0)
55-65 years old	0 (0.8)	1 (0.2)	1 (1.0)
65+ years old	0 (2.3)	3 (0.7)	3 (3.0)
Total	120 (120.0)	34 (34.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 31: Contingency table of the variables "age" and "willingness to pay (high price difference, different airlines)".

Education and willingness to pay (low price difference) The following variables to be tested are "education" and "willingness to pay (low price difference)". Figure 42 below represents the variables' absolute frequencies.

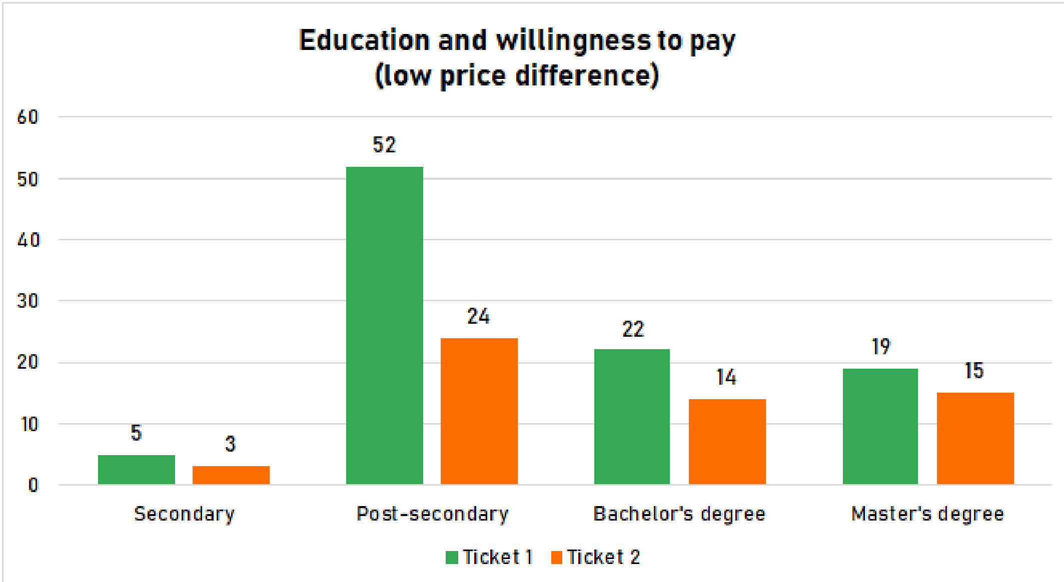

Figure 42: Absolute frequencies of the variables "education" and "willingness to pay (low price difference)".

The below-represented table (Table 32) illustrates the variables' absolute and expected frequencies, composing the contingency table of the variables "education" and "willingness to pay (low price difference)". The chi-squared value obtained from testing the following pair of variables is equal to $\chi^2(3, N = 154) = 1.7390$, exhibiting a p-value of 0.628. Since $0.628 > \alpha = 0.05$, we fail to reject the null hypothesis H_0, leading us to the conclusion that does not exist any association between the variables "education" and "willingness to pay (low price difference)".

Therefore, according to this result, respondents decide to pay extra to offset carbon emissions from their flights regardless of their education degree when the VCO involves a low price difference.

Education	*Willingness to pay (low price difference)*		**Total**
	Ticket 2	**Ticket 1**	
Secondary	3	1	4
	(2.9)	(5.1)	(4.0)
Post-secondary	24	52	76
	(27.6)	(48.4)	(76.0)
Bachelor's Degree	14	22	36
	(13.1)	(22.9)	(36.0)
Master's Degree	15	19	34
	(12.4)	(21.6)	(34.0)
Total	56	98	154
	(56.0)	(98.0)	(154.0)

Absolute frequencies and (expected frequencies)

Table 32: Contingency table of the variables "education" and "willingness to pay (low price difference)".

Education and willingness to pay (high price difference, different airlines) The next couple of variables that will be analyzed are "education" and "willingness to pay (high price difference, different airlines)". Figure 43 below graphically illustrates the absolute frequencies of the variables concerned.

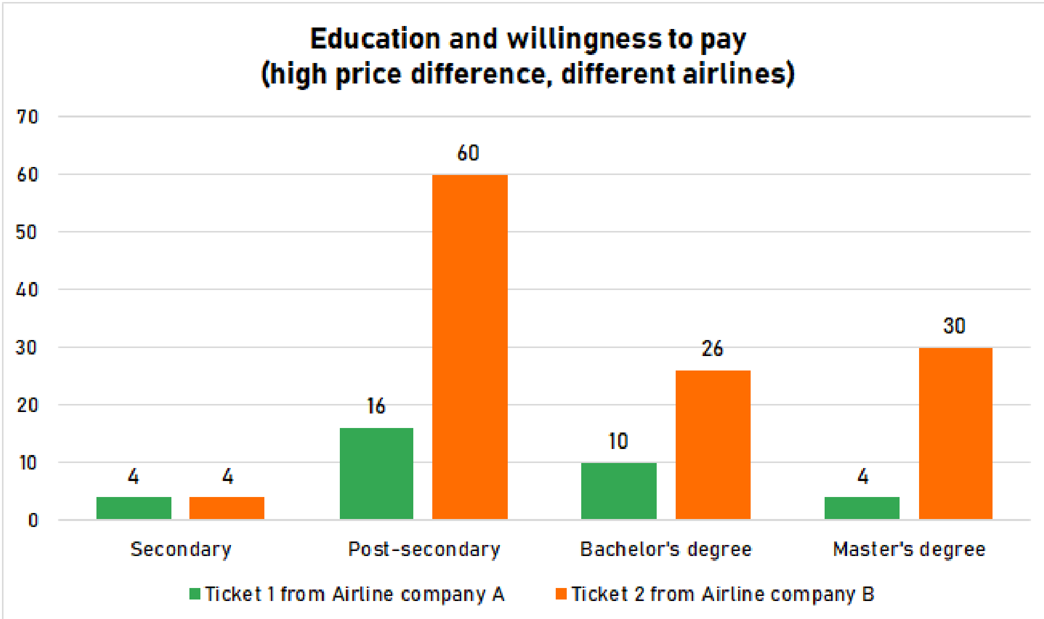

Figure 43: Absolute frequencies of the variables "education" and "willingness to pay (high price difference, different airlines)".

The contingency table for the variables "education" and "willingness to pay (low price difference)" is represented by Table 33 below. The chi-squared test for this pair of variables gives us the result of $\chi^2(3, N = 154) = 6.4539$, with a p-value $= 0.092$. As $0.092 > \alpha = 0.05$, we fail to reject H_0, confirming that there is no association between the variables analyzed.

Education	*Willingness to pay (high price difference, different airlines)* **Ticket 2 from Airline company B**	**Ticket 1 from Airline company A**	**Total**
Secondary	4 (6.2)	4 (1.8)	4 (4.0)
Post-secondary	60 (59.2)	16 (16.8)	76 (76.0)
Bachelor's Degree	26 (28.1)	10 (7.9)	36 (36.0)
Master's Degree	30 (26.5)	4 (7.5)	34 (34.0)
Total	120 (120.0)	34 (34.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 33: Contingency table of the variables "education" and "willingness to pay (high price difference, different airlines)".

Air travel frequency and willingness to pay (low price difference) The next pair of variables under analysis are "air travel frequency" and "willingness to pay (low price difference)". Absolute frequencies of the variables concerned are visually illustrated by Figure 44.

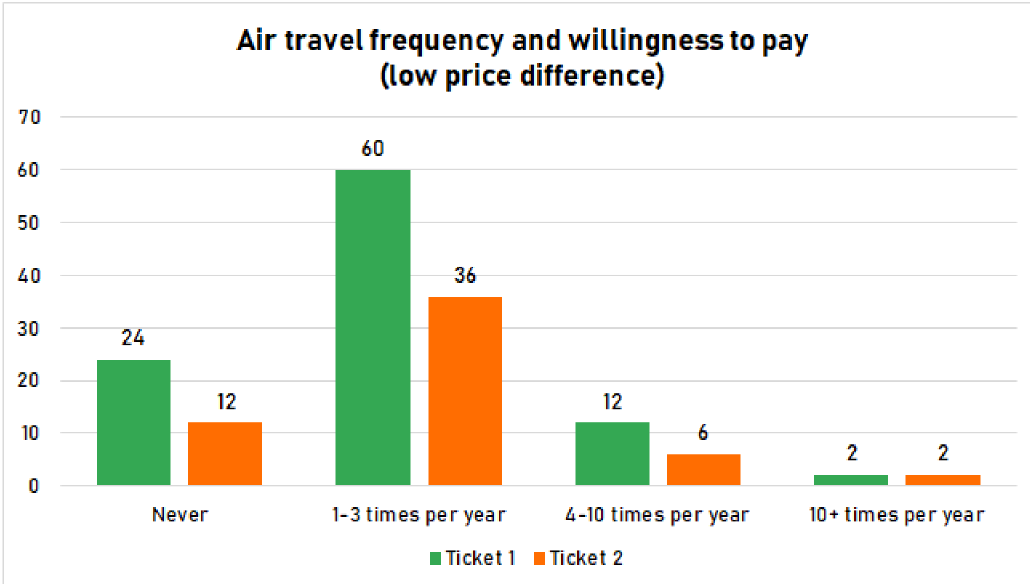

Figure 44: Absolute frequencies of the variables "air travel frequency" and "willingness to pay (low price difference)".

Table 34 below represents the contingency table for the variables "air travel frequency" and "willingness to pay (low price difference)". The chi-squared value obtained by testing these two variables equals to $\chi^2(3, N = 154) = 0.5893$, exhibiting a p-value corresponding to 0.899. As the p-value is considerably higher than the significance level $\alpha = 0.05$, we fail to reject H_0, concluding that there is no association between the variables under analysis.

Therefore, irrespective of the respondents' frequency of air travel, they will voluntarily pay more for their flight tickets to offset carbon emissions when a low price difference is involved.

Air travel frequency	*Willingness to pay (low price difference)* Ticket 2	Ticket 1	**Total**
Never	12 (13.1)	24 (22.9)	36 (36.0)
1-3 times per year	36 (34.9)	60 (61.1)	96 (96.0)
4-10 times per year	6 (6.5)	12 (11.5)	18 (18.0)
10+ times per year	2 (1.5)	2 (2.5)	4 (4.0)
Total	56 (56.0)	98 (98.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 34: Contingency table of the variables "air travel frequency" and "willingness to pay (low price difference)".

Air travel frequency and willingness to pay (high price difference, different airlines) Now, we are going to perform a chi-squared test for the variables "air travel frequency" and "willingness to pay (high price difference, different airlines)". Figure 45 below graphically represents the absolute frequencies of the variables concerned.

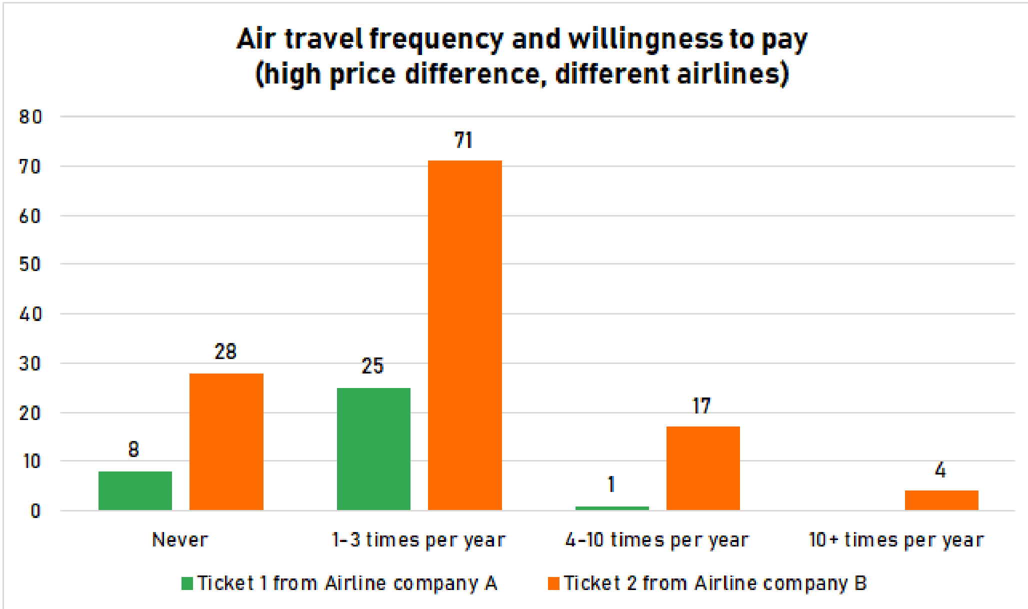

Figure 45: Absolute frequencies of the variables "air travel frequency" and "willingness to pay (high price difference, different airlines)".

Then, the table below (Table 35) illustrates the absolute and expected frequencies constiting the contigency table of the variables "air travel frequency" and "willingness to pay (high price difference, different airlines)". The chi-squared test for these two variables gives us the result of $\chi^2(3, N = 154) = 4.8668$, with a p-value = 0.182. As $0.182 > \alpha = 0.05$, we fail to reject the null hypothesis H_0, leading us to the conclusion that there is no association between the two variables analyzed.

Air travel frequency	*Willingness to pay (high price difference, different airlines)*		**Total**
	Ticket 2 from Airline company B	**Ticket 1 from Airline company A**	
Never	28 (28.1)	8 (7.9)	36 (36.0)
1-3 times per year	71 (74.8)	25 (21.2)	96 (96.0)
4-10 times per year	17 (14.0)	1 (4.0)	18 (18.0)
10+ times per year	4 (3.1)	0 (0.9)	4 (4.0)
Total	120 (120.0)	34 (34.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 35: Contingency table of the variables "air travel frequency" and "willingness to pay (high price difference, different airlines)".

Climate awareness and willingness to pay (low price difference) The next variables under analysis are "climate awareness" and "willingness to pay (low price difference)". Figure 46 below illustrates the absolute frequencies of the variables concerned.

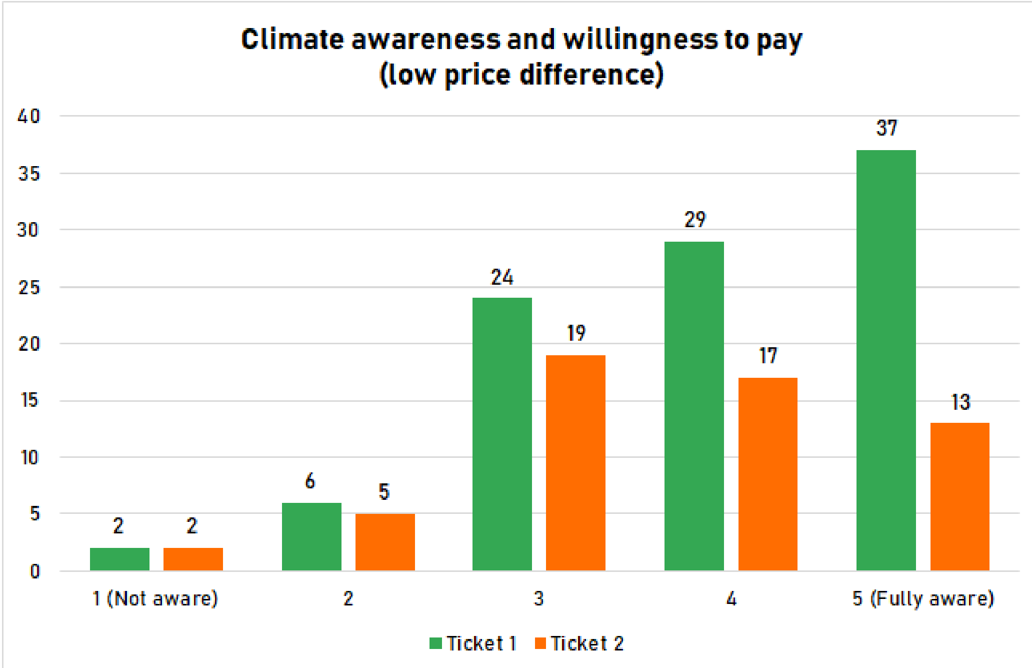

Figure 46: Absolute frequencies of the variables "climate awareness" and "willingness to pay (low price difference)".

The contingency table of the variables "climate awareness" and "willingness to pay (low price difference)" is represented by Table 36 below. The chi-squared value obtained by testing the two variables is equal to $\chi^2(4, N = 154) = 4.1790$, exhibiting a p-value equal to 0.382. As 0.382 results higher than the significance level $\alpha = 0.05$, we fail to reject our null hypothesis, confirming the absence of association between the variables "climate awareness" and "willingness to pay (low price difference)".

As a result, respondents will voluntarily choose to pay more to offset carbon emissions from their flights when a low price difference is involved, irrespective of their level of awareness concerning environmental concerns. Hence, even if respondents exhibit a lower degree of climate awareness, they will still choose to pay more for VCOs.

Climate awareness	*Willingness to pay (low price difference)*		**Total**
	Ticket 2	**Ticket 1**	
1 (Not aware)	2 (1.5)	2 (2.5)	4 (4.0)
2	5 (4.0)	6 (7.0)	11 (11.0)
3	19 (15.6)	24 (27.4)	43 (43.0)
4	17 (16.7)	29 (29.3)	46 (46.0)
5 (Fully aware)	13 (18.2)	37 (31.8)	50 (50.0)
Total	56 (56.0)	98 (98.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 36: Contingency table of the variables "climate awareness" and "willingness to pay (low price difference)".

Climate awareness and willingness to pay (high price difference, different airlines)

The following variables that we are going to analyze under the chi-squared test are "climate awareness" and "willingness to pay (high price difference, different airlines)". Figure 47 below illustrates the absolute frequencies of the abovementioned variables.

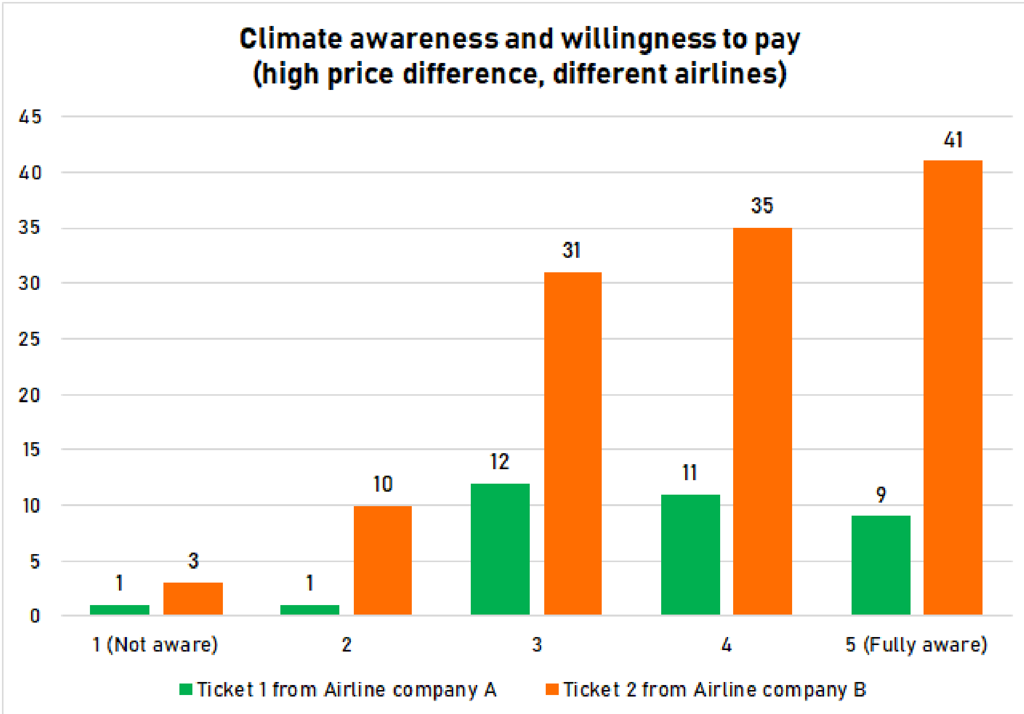

Figure 47: Absolute frequencies of the variables "climate awareness" and "willingness to pay (high price difference, different airlines)".

Table 37 below represents the absolute and expected frequency for the variables "climate awareness" and "willingness to pay (high price difference, different airlines)", constituting the contingency table. The chi-squared value obtained by testing the two variables results equal to $\chi^2(4, N = 154) = 2.5209$, with a p-value = 0.641. As the p-value obtained is visually higher than the significance level $\alpha = 0.05$, we fail to reject the null hypothesis H_0, determining no association between the variables analyzed.

As a result, when faced with a very high price difference and with the alternative of choosing a more eco-friendly airline, respondents choose not to spend more for VCOs to offset their emissions and thus decide to support the airline not proposing "green fares", regardless of the respondents' level of awareness of climate concerns.

Climate awareness	*Willingness to pay (high price difference, different airlines)*		Total
	Ticket 2 from Airline company B	**Ticket 1 from Airline company A**	
1 (Not aware)	3 (3.1)	1 (0.9)	4 (4.0)
2	10 (8.6)	1 (2.4)	11 (11.0)
3	31 (33.5)	12 (9.5)	43 (43.0)
4	35 (35.8)	11 (10.2)	46 (46.0)
5 (Fully aware)	41 (39.0)	9 (11.0)	50 (50.0)
Total	120 (120.0)	34 (34.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 37: Contingency table of the variables "climate awareness" and "willingness to pay (high price difference, different airlines)".

Air travel environmental impact awareness and relevance of air travel impact on climate change The following variables under analysis are "air travel environmental impact awareness" and "relevance of air travel impact on climate change". This analysis focuses on whether there is an association between respondents' degrees of awareness concerning the impact of air travel on the environment and the relevance they attribute to specific aviation's environmental impact on climate change. Figure 48 below illustrates the absolute frequencies for the variables under analysis.

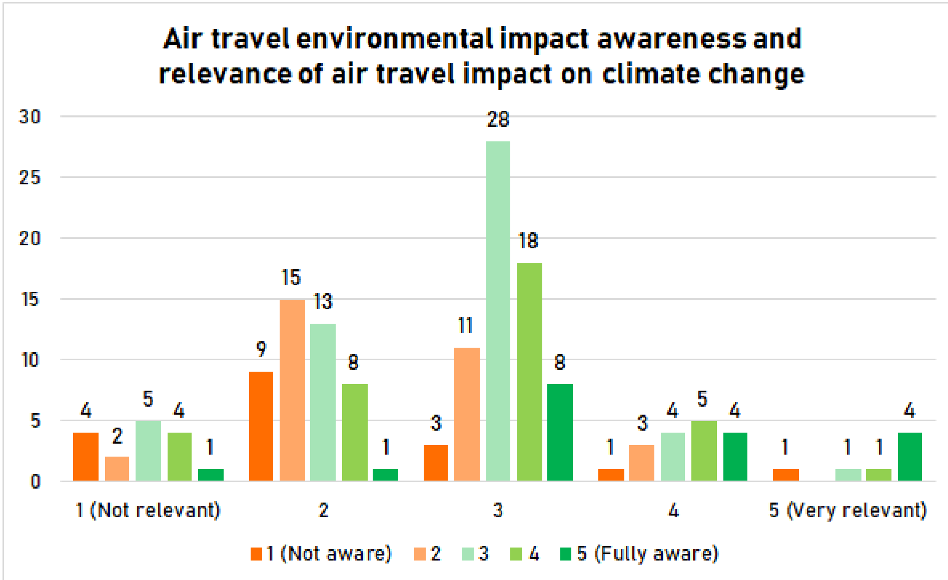

Figure 48: Absolute frequencies of the variables "air travel environmental impact awareness" and "relevance of air travel impact on climate change".

The contigency table of the variables "air travel environmental impact awareness" and "relevance of air travel impact on climate change" is represented below by Table 38. The chi-squared test performed on the variables concerned provides us the result of $\chi^2(16, N = 154) = 37.2831$, with a p-value corresponding to 0.002. In this case, the p-value is less than the significance level $\alpha = 0.05$, leading to the rejection of the null hypothesis H_0. As a result, there is an association between the variables under analysis.

In particular, respondents who claimed to be aware at degree 3 of the environmental impact of air travel also declared to attribute the same degree of relevance to air travel impact on climate change.

Air travel environmental impact awareness	*Relevance of air travel impact on climate change* 1 (Not relevant)	2	3	4	5 (Very relevant)	**Total**
1 (Not aware)	4 (1.9)	9 (5.4)	3 (7.9)	1 (2.0)	1 (0.8)	18 (18.0)
2	2 (3.2)	15 (9.3)	11 (13.7)	3 (3.4)	0 (1.4)	31 (31.0)
3	5 (5.3)	13 (15.2)	28 (22.5)	4 (5.6)	1 (2.3)	51 (51.0)
4	4 (3.7)	8 (10.8)	18 (15.9)	5 (4.0)	1 (1.6)	36 (36.0)
5 (Fully aware)	1 (1.9)	1 (5.4)	8 (7.9)	4 (2.0)	4 (0.8)	18 (18.0)
Total	16 (16.0)	46 (46.0)	68 (68.0)	17 (17.0)	7 (7.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 38: Contingency table of the variables "air travel environmental impact awareness" and "relevance of air travel impact on climate change".

Air travel environmental impact awareness and relevance of air travel impact on air quality Analogously to the previous analysis, we will test the variables "air travel environmental impact awareness" and "relevance of air travel impact on air quality", considering the second specific environmental impact related to air travel. The absolute frequencies of the two variables are graphically illustrated by Figure 49 below.

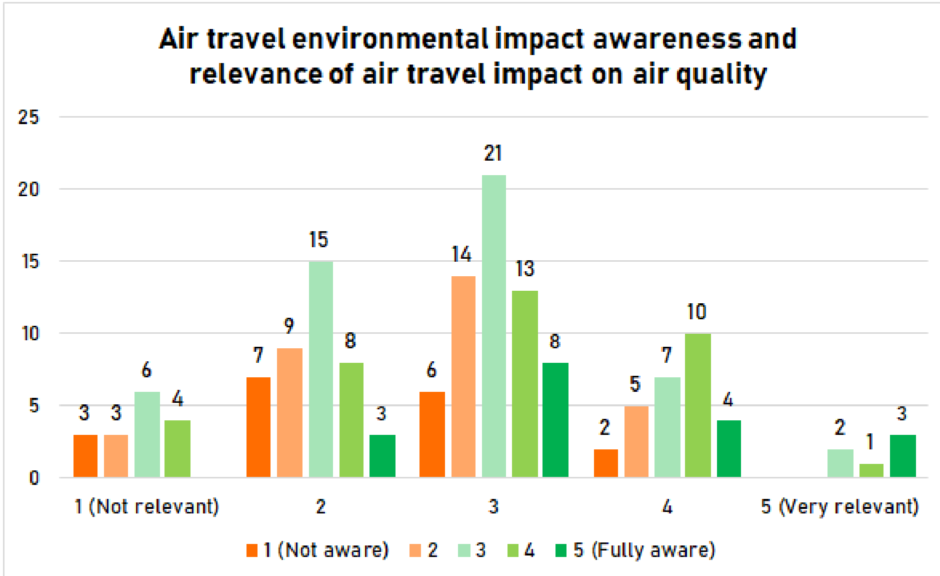

Figure 49: Absolute frequencies of the variables "air travel environmental impact awareness" and "relevance of air travel impact on air quality".

Table 39 below represents the contingency table of the variables "air travel environmental impact awareness" and "relevance of air travel impact on air quality". The chi-squared value obtained from testing the two variables is equal to $\chi^2(16, N = 154) = 18.0796$, exhibiting a p-value equal to 0.319. As $0.319 > \alpha = 0.05$, we fail to reject H_0, concluding that there is no association between variables.

Contrary to the previous analysis, respondents demonstrated that they attribute different relevance levels to air travel's impact on air quality irrespective of their level of awareness regarding air travel's impact on the environment as a whole.

Air travel environmental impact awareness	*Relevance of air travel impact on air quality* **1 (Not relevant)**	**2**	**3**	**4**	**5 (Very relevant)**	**Total**
1 (Not aware)	3 (1.9)	7 (4.9)	6 (7.2)	2 (3.3)	0 (0.7)	18 (18.0)
2	3 (3.2)	9 (8.5)	14 (12.5)	5 (5.6)	0 (1.2)	31 (31.0)
3	6 (5.3)	15 (13.9)	21 (20.5)	7 (9.3)	2 (2.0)	51 (51.0)
4	4 (3.7)	8 (9.8)	13 (14.5)	10 (6.5)	1 (1.4)	36 (36.0)
5 (Fully aware)	0 (1.9)	3 (4.9)	8 (7.2)	4 (3.3)	3 (0.7)	18 (18.0)
Total	16 (16.0)	42 (42.0)	62 (62.0)	28 (28.0)	6 (6.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 39: Contingency table of the variables "air travel environmental impact awareness" and "relevance of air travel impact on air quality".

Air travel environmental impact awareness and relevance of air travel impact on noise pollution The last two variables under analysis are "air travel environmental impact awareness" and "relevance of air travel impact on noise pollution", considering the last specific environmental impact relative to air travel. Figure 50 below graphically illustrates the absolute frequencies of the variables concerned.

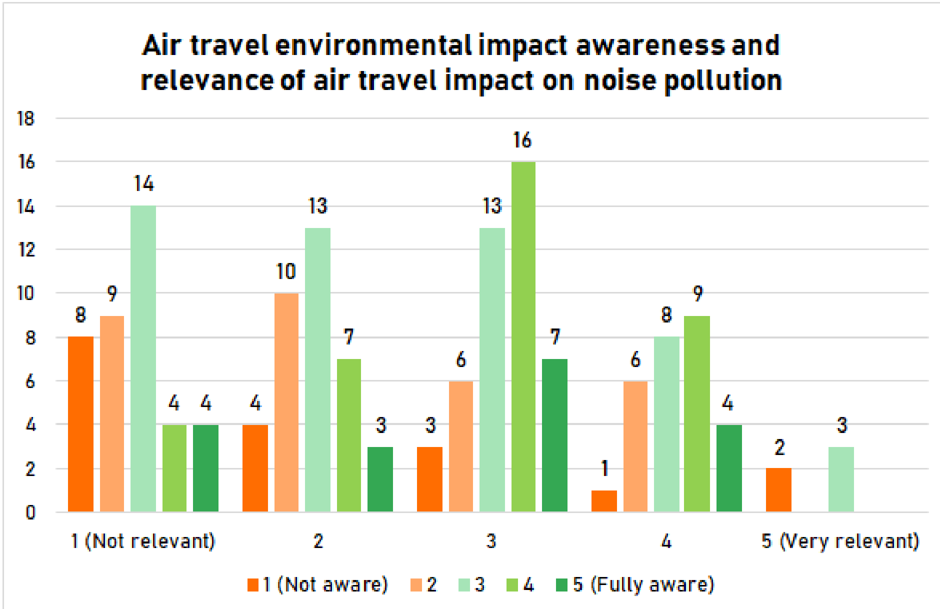

Figure 50: Absolute frequencies of the variables "air travel environmental impact awareness" and "relevance of air travel impact on noise pollution".

Then, the absolute and expected frequencies constituting the contingency table are represented below by Table 40. The chi-squared test for the two variables provided us the result of $\chi^2(16, N = 154) = 23.2782$, exhibiting a p-value = 0.106. As $0.106 > \alpha = 0.05$, we fail to reject H_0, determining no association between the variables under analysis.

Hence, similiarly to the previous analysis, respondents demonstrated that they attribute different relevance levels to air travel's impact on noise pollution irrespective of their level of awareness regarding air travel's impact on the environment as a whole.

Air travel environmental impact awareness	*Relevance of air travel impact on noise pollution* 1 (Not relevant)	2	3	4	5 (Very relevant)	**Total**
1 (Not aware)	8 (4.6)	4 (4.3)	3 (5.3)	1 (3.3)	2 (0.6)	18 (18.0)
2	9 (7.9)	10 (7.4)	6 (9.1)	6 (5.6)	0 (1.0)	31 (31.0)
3	14 (12.9)	13 (12.3)	13 (14.9)	8 (9.3)	3 (1.7)	51 (51.0)
4	4 (9.1)	7 (8.6)	16 (10.5)	9 (6.5)	0 (1.2)	36 (36.0)
5 (Fully aware)	4 (4.6)	3 (4.3)	7 (5.3)	4 (3.3)	0 (0.6)	18 (18.0)
Total	39 (39.0)	37 (37.0)	45 (45.0)	28 (28.0)	5 (5.0)	154 (154.0)

Absolute frequencies and (expected frequencies)

Table 40: Contingency table of the variables "air travel environmental impact awareness" and "relevance of air travel impact on noise pollution".

4.3 Conclusions on the survey

Based on the analysis above, we can draw several conclusions, both in line with and in contrast to what was previously ascertained.

Level of climate awareness In particular, concerning the level of respondents' awareness of environmental concerns and the climate emergency as a whole, it is visible that, in recent years, the importance of preserving the environment and the critical issue of climate change has reached considerable engagement from individuals, boosting substantially their degree of climate awareness. From the survey results, in fact, we can observe that 32.5% of respondents declared to be "fully aware" (degree 5) of climate concerns, immediately followed by 29.9% who claimed to be aware at degree 4 and 27.9% at degree 3. Furthermore, this climate awareness, by the chi-squared test performed, is displayed to exist regardless of gender, age, and education of respondents. These findings result in contrast with what has been mentioned in the literature review; in particular, some studies claimed that younger individuals and those possessing a higher degree of education tend to be more aware of climate and environmental concerns and then more prone to voluntary offset carbon emissions in the case of airlines proposing them flight tickets surcharged by "green fares" (Zhang et al., 2019)(B. W. Ritchie et al., 2021)(Segerstedt & Grote, 2016).

Voluntary Carbon Offsettings (VCOs) and willingness to pay Concerning "green fares" and again in contrast with the literature review, our survey's findings demonstrated that respondents are willing to pay a low price difference (e.g., EUR 10,00) for their flight ticket to offset emissions from their flights irrespective of their gender, age, education, and income, contributing to climate change mitigation programs implemented by airlines through VCOs. Again, the literature findings concerning the relationship between individuals' climate awareness and willingness to pay for "green fares" results in contrast with our survey results. In particular, some studies claimed that more climate aware individuals are more prone to offset their emissions and thus accept VCOs proposed by airlines (Yohan Kim & Ko, 2016)(Ropret Homar & Knežević Cvelbar, 2024). However, our survey analysis revealed that both fully aware and not aware respondents are willing to pay a little price difference to offset their emissions from their flights. In particular, 63.6% of the respondents claimed that they would buy the flight ticket surcharged by the "green fare" when a low price difference is involved. Furthermore, the chi-squared test demonstrated the absence of an association between respondents' level of climate awareness and the willingness to pay for VCOs. Concerning the association between individuals' air travel frequency and their willingness to pay for "green fares", some studies claimed that frequent air travelers are more reluctant to offset emissions through VCOs (B. W. Ritchie et al., 2021)(Rotaris et al., 2020), while others highlighted the opposite (Akter et al., 2009). However, our findings exhibited that respondents' air travel frequency does not affect their willingness to pay, demonstrating that for a slight price difference, both frequent air travelers and those who do not travel at all would be willing to adhere to VCOs proposed by airlines to contribute to climate change mitigation.
Nevertheless, despite most respondents demonstrating their willingness to pay a slight price difference to adhere to VCOs proposed by airlines, the situation drastically changes when they are facing a considerably high price difference (e.g., EUR 35,00), even if the respective flight tickets are offered by two different airlines, leaving them the option to choose and support the more sustainable airline. In particular, 77.9% of the respondents claimed not to be willing to pay such a price difference to offset emissions from their flight; and, more surprisingly, the chi-squared test exhibited that, at significance level $\alpha = 0.05$, younger individuals are more reluctant to purchase a flight ticket when a considerable price difference is involved.

Air travel environmental impact awareness and perceived relevance Respondents displayed a slightly lower degree of awareness regarding air travel's environmental impact than those exhibited in the context of general climate and environmental concerns. In particular, 11.7% of respondents declared to be "fully aware" of air travel's impact on the environment, compared to the 32.7% "fully aware" of general climate concerns. Again, a higher share of respondents, corresponding to 11.7%, declared to be "not aware" of the environmental impact of air travel, compared to 2.6%, which claimed to be "not aware" of general climate concerns. Concerning these results, the chi-squared test performed between the level of awareness of air travel's impact on the environment and the one of climate concerns exhibited, at significance level $\alpha = 0.05$, an association between the two results. In particular, respondents who showed some level of awareness of climate concerns also exhibited some awareness in the context of the environmental impact caused by aircraft engines, and those who did not exhibit any level of awareness of the environmental effects of air travel neither demonstrated it in the context of climate concerns. In addition, concerning the specific environmental impacts stemming from air travel, respondents, on average, deemed the impacts on air quality and climate change as the most relevant, considering the ones on noise pollution as the least relevant. These results may be explained by the advancements in aviation technology, enabling the manufacturing of quieter aircraft. In particular, in the last three decades, single aircraft noise production has been reduced by 75% (EC, 2024a). Furthermore, thanks to the survey's question analyzing respondents' knowledge concerning aviation's share of carbon emissions, we ascertained a considerable lack of knowledge surrounding this topic. In particular, most respondents overestimated the share of energy-related CO_2 emissions for which they believe the aviation industry is accountable: 42.9% of respondents believe that the aviation industry's responsibility for CO_2 emissions is around 10%, 21.4% thought it to be around 7%, and 20.1% claimed it to be around 21%. Only 14.9% of respondents picked the correct answer of "around 2%". These findings underscore the need to address misconceptions surrounding the environmental impact of aviation.

Decarbonization in the aviation industry In line with the findings of the literature, our results highlighted that most respondents believe that technological innovation, sustainable aviation fuel (SAF) employment, and operational refinements could be the best decarbonization strategies to be applied in the aviation industry. In particular, several studies claimed that airlines' sustainability objectives (i.e., emission intensity reduction) could be attained at best by employing new technologies, sustainable aviation fuel (SAF), and operational improvements (Agarwal, 2009)(Ficca et al., 2023). However, due to the currently limited technological profile of the aviation sector, next-generation technology (i.e., hybrid and electric aircraft) is still unavailable in the short-run perspective, making sustainable aviation fuel (SAF) the decarbonization solution with the highest potential. In contrast, 51.3% of respondents believed new technology to be the best aviation industry's decarbonization strategy, immediately followed by sustainable aviation fuel (SAF) employment (16.9%), operational enhancements (15.6%), mandatory carbon offsetting programs (6.5%), voluntary carbon offsetting programs (5.8%), and sustainable cabin practices (3.2%). In line with the findings of the literature (Sonnenschein & Mundaca, 2019)(Sonnenschein & Smedby, 2019), a larger share of respondents believe that mandatory carbon offsetting programs, such as CORSIA and EU ETS, are the best tools for pursuing a decarbonization path rather than VCOs.

Corporate Sustainability in Airlines: "greenwashing" or true commitment? Many airlines disclose their accountability to stakeholders and passengers through sustainability reporting, with the objective of increasing their green reputation and informing stakeholders of their genuine commitment to sustainable development. Through *Question 11*, we analyzed respondents' beliefs regarding sustainability efforts undertaken by airlines. Surprisingly, results revealed that a considerable share of respondents (77.9%) are aware of the climate emergency but still do not trust businesses' corporate sustainability efforts, which are deemed to generate "greenwashing" and be adopted only for profit purposes. These results may explain the considerable share of respondents in *Question 10 B.* who were unwilling to pay a huge price difference to support a more sustainable airline employing a VCO program in its sustainability strategy rather than the other who does not, offering a lower price. Additionally, according to the findings of the literature, VCOs are not often seen as "sincere" tools in terms of commitment to sustainability. In particular, according to a recent study, airlines might choose to implement voluntary carbon offsettings (VCOs) only to enhance their green reputation and perhaps incur the risk of "greenwashing" (Knorr & Eisenkopf, 2020).

5 Conclusions

Climate change stands as one of the most urgent issues nowadays, and businesses, significant drivers of productivity and thus severely impacting the external environment, are endeavoring to address it through their corporate sustainability efforts from the perspective of the environmental dimension. Air travel, constituting one of the means of transport connecting people and cultures from one point to another on a global scale, is expected to increase in demand at an unprecedented rate in the following decades, leading to a related increase in its associated emissions deriving from aircraft engines. In light of the urgent climate concerns and the expected significant surge in air travel demand, airlines must increasingly cooperate with policymakers and legislators to firmly address environmental issues. In particular, this work aspires to entirely focus on the environmental impact caused by air travel, providing a theoretical overview of the principal environmental impacts caused by air traffic and how airlines are cooperating with legislators, policymakers, governments, and other industry stakeholders to effectively combat the current climate emergency by establishing an effective decarbonization path embedded to their sustainability strategies designed to permit to the industry to reach the ambitious goal of net zero by 2050. After outlining which are the most notable impacts stemming from daily air travel and how legislators and institutions are undertaking initiatives to incentivize airlines to pollute less, this research also aspires to understand end-users' perceptions and level of knowledge towards the present climate concerns deriving from air travel and which are their personal beliefs concerning the corporate sustainability efforts undertaken by airlines.

This research starts by providing a theoretical introduction to the historical development of the concept of sustainability that materialized since the first signs of environmental degradation noticed during the 20th century and describing the main peculiarities that characterized the emergence of the concept of "sustainable development". In particular, the evolution of the sustainability concept in the last decades led to several historical and political events occurring at the international and European levels, which have collectively shaped the current status of the three pillars of sustainability and the importance of corporate sustainability. From this first introduction, it emerged how sustainability is gaining momentum, especially among businesses, as a result of the legislative initiatives proposed by the European Union in terms of sustainability reporting, increasingly requiring companies to disclose their accountability in the context of corporate sustainability efforts. In particular, the Corporate Sustainability Reporting Directive (CSRD) perfectionated the previous Non-Financial Reporting Directive (NFRD) terms, requirements, and concept of double materiality and has extended its scope, requiring an increased number of types of companies to perform their sustainability reporting accordingly to the incoming European Sustainability Reporting Standards (ESRS) to be introduced. After introducing the broad concept of corporate sustainability and sustainability reporting, this research proceeds by presenting its core topics: the aviation industry, its related environmental impacts, and how airlines are embedding sustainability practices in their businesses. From the following specific analysis, the principal environmental impacts of air travel and to what extent they affect the external environment emerged. In particular, it can be observed how air travel has significant implications on climate change and air quality due to the amount of nocive gases, both CO_2 and non-CO_2 (e.g., H_2O, NO_X, contrails), released by aircraft engines and their related effects on the environment. Then, aircraft's impact on noise pollution has demonstrated notable progress in the last three decades: technological innovation has, in particular, permitted the reduction of 75% of a single aircraft's noise emissions since then. Notably, given the increasing importance of sustainability reporting and accountability disclosure, the Sustainability Accounting Standards Board (SASB) designed tailored sustainability reporting standards for airlines to enable clarity and comparability, which are deemed vital features for a reliable sustainability report. In addition, due to the expected sumptuous air travel demand growth for the next decades and the ever-increasing climate concerns, legislators and policymakers acknowledged airlines as potential contributors to carbon emission reductions thanks to their sustainability efforts, contributing thus to the climate change mitigation objectives prescribed by the European Taxonomy Regulation. In particular, in light of what was mentioned earlier, the European Commission recently amended the European Taxonomy's Delegated Regulation (Delegated Regulation (EU) 2013/2485), including four aviation-related core business activities as transition activities falling under the EU taxonomy's scope. Although the performance of the alignment prescribed by the EU Taxonomy applicability is required to be performed by businesses as of reporting year 2024, many airlines have begun to release in their sustainability reports for FY2023 the eligibility analysis based on the new technical screening criteria associated with the aviation-related business activities introduced by the Delegated Regulation (EU) 2013/2485. By analyzing the technical screening criteria associated with the four aviation-related business activities introduced by the Delegated Regulation (EU) 2013/2485 and comparing IATA's reports concerning possible decarbonization paths airlines could follow to reach the net zero goal by 2050 effectively, we can conclude which decarbonization strategies airlines should pursue to best achieve their sustainability objectives. It emerged that despite next-generation technological innovation in the aviation industry (e.g., hybrid and electric aircraft) having the capability of delivering substantial emission reductions, the latter is currently unavailable from a short-run perspective due to the aviation sector's limited technological profile. According to IATA's reports, instead, sustainable aviation fuel (SAF) turns out to be the strategy with the highest potential for effectiveness, expected to deliver 65% of emission reductions. Following the SAF's employment effectiveness in reducing emissions emphasized by IATA, the latter then highlights the importance for airlines to pursue operational and infrastructure improvements, such as the ones introduced by ambitious projects such as the Single European Sky, NextGen, and the ICAO Aviation System Block Upgrades (ASBU). Other essential steps undertaken by policymakers and institutions in the aviation industry in terms of policy instruments vaulted at reducing emissions are the introduction of the CORSIA scheme at the international level and the already in-force European Emission Trading System (ETS) for the aviation sector, which consist of market-based measures (MBMs) (i.e., mandatory carbon offsetting schemes) geared towards reducing carbon emissions and fight climate change in a cost-efficient manner in line with the Paris Agreement and EU climate objectives. Again, concerning policy instruments, eventual carbon and fuel taxes have been deemed by many studies and airlines themselves as policy instruments capable of producing significant distortions in competition if not applied consistently trough the establishment international agreements. Furthermore, despite many airlines still adopting voluntary carbon offsetting schemes as part of their sustainability strategies, many studies deemed VCOs highly ineffective compared to the decarbonization strategies mentioned above due to the low share of passengers willing to pay to compensate for emissions from their flights.

By closely analyzing four different airlines' sustainability strategies from the environmental perspective, it can be noticed how their main strategies pursued are consistent with what has been mentioned above. In particular, most airlines are concentrating a considerable part of their resources on implementing a fleet renewal strategy as part of their sustainability efforts. This strategy involves modernizing their fleet with new-generation aircraft designed to be quieter and more fuel-efficient, in alignment with ICAO's Chapter 4 and Chapter 14 Noise Standards. This approach enables airlines to achieve significant emission reductions, allowing them to decrease their emission intensity accordingly. Then, in recent years, despite the high prices dictated by the sustainable aviation fuel (SAF) market, airlines are slowly approaching SAF's employment, increasing the share of SAF blended with traditional jet fuel (i.e., kerosene) in their flights every year. In addition, fleet renewal with more fuel-efficient and quieter aircraft and increasing SAF's employment are also incentivized by the new EU Taxonomy technical screening criteria for aviation-related economic activities.

The survey revealed that respondents are collectively almost fully aware of climate concerns. On the other hand, respondents proved to be less aware of the specific environmental impacts caused by air travel. They also displayed extremely limited knowledge concerning the share of energy-related carbon emissions for which the aviation industry is accountable. In particular, more than half of the sample overestimated the environmental impact of aviation in terms of carbon emissions, believing it to be responsible for shares ranging from around 7% to around 21% of energy-related CO_2 emissions when, in reality, it accounts for "only" around 2%. These findings underscore the need to address misconceptions about climate change as a whole and the environmental impact of aviation. Furthermore, 77.9% of respondents declared not to trust airlines' (and businesses') corporate sustainability efforts, being considered only as ways to enhance their "green" reputation and profits and thus generate greenwashing. These findings outline the need for businesses to inform more end-users about economic activities' specific impacts on the external environment and the climate and to incentivize stakeholders to carefully consult the companies' sustainability reports, which need to be clear, comparable, verified by scientific evidence, and reliable. However, the applicability of the incoming mandatory sustainability reporting standards (ESRS) and the enhancements prescribed by the new Corporate Sustainability Reporting Directive (CSRD) will undoubtedly play a crucial role in increasing end-users' trust in companies, leading them to support companies that exhibit a more sustainable behavior. By supporting sustainable companies, the resultant collective efforts undertaken by consumers, stakeholders, and businesses will promote sustainable development in all dimensions. However, concerning the survey analysis, the sample analyzed, even if it covers respondents aged between less than 18 years old to more than 65 years old, older respondents are present in a significantly lower amount, which can constitute a limit in this study. In particular, most studies mentioned in the literature review emphasized that younger individuals tend to be more climate-aware than older ones. In contrast, our findings outlined the opposite, perhaps due to the smallest number of older respondents.

Concerning the analysis of the sustainability reports of the four different airlines, we can observe that only 3 out of 4 airlines adopted the Sustainability Accounting Standards Board (SASB) standards designed for airlines, leading to a mild incomparability between the other reports. However, the wide adoption of the tailored Sustainability Accounting Standards Board (SASB) standards for airlines would facilitate the comparison between the metrics and activity metrics of different airlines under analysis, facilitating and guiding investors' decisions when analyzing sustainability considerations.

In light of this study's findings, further research on end-users' level of knowledge about sustainability concerns would be helpful in understanding better the misconceptions surrounding climate concerns that emerged from our research. In particular, it would be compelling to investigate, through a tailored survey research, end-users' level of knowledge concerning the climate impact of each mode of transport, as respondents in our research overestimated in an excessive way the share of energy-related CO_2 for which the aviation industry is responsible. Furthermore, in light of the findings regarding respondents' sustainability beliefs, it emerged that a considerable share of respondents believe in the climate emergency, but considering airlines' (and businesses') sustainability efforts merely greenwashing. Accordingly, it would be interesting and useful (especially for businesses) to understand, through survey research, the reasons pushing end-users to distrust businesses' corporate sustainability efforts and what businesses themselves could do to provide reasons for their stakeholders to trust them. Then, in the same survey, it would be even more compelling to ask stakeholders how and to what extent more stringent directives and regulations as part of sustainability reporting would affect the level of confidence they put in businesses, changing their sustainability beliefs accordingly. In conclusion, as mentioned before, in scrutinizing the four airlines' sustainability reportings under examination, only 3 out of 4 reports used the Sustainability Accounting Standards Board (SASB) airlines' standards. If extensively implemented by all airlines, these industry-specific standards significantly strengthen the level of comparability between sustainability reports, as they highlight the principal metrics and activity metrics relative to airlines. Given these facts, it would be interesting to investigate how many airline companies worldwide effectively implement the SASB industry-specific standards in their reports.

Appendix A Questions

Appendix A.1 Demographic questions

Question 1 *What is your gender?*

- *Male*
- *Female*

Question 2 *What is your age?*

- Less than 18 years old
- 18-25 years old
- 26-40 years old
- 41-54 years old
- 55-65 years old
- 65+ years old

Question 3 *What is your level of education?*

- Elementary
- Secondary
- Post-secondary
- Bachelor's degree
- Master's degree
- PhD degree

Question 4 *Which is your level of income?*

- less than or equal to EUR 20,000
- between EUR 20,000 - EUR 50,000
- between EUR 50,000 - EUR 100,000
- more than EUR 100,000

Appendix A.2 Survey-specific questions

Question 5 *How much are you aware of the impacts of climate change on our planet? Rate your climate awareness on a scale from 1 to 5.*
This question aims to discover respondents' awareness of climate change, the "rate of climate-concern". After analyzing all the responses, we will obtain different percentages (%) of respondents displaying their level of "climate-awareness".

Question 6 *On average, how often do you travel by air in one year?*
This question helps to comprehend how often respondents travel by air and if those who frequently travel on airplanes are effectively "climate-aware" compared to those who never travel.
Different alternatives are provided to determine respondents' suitable options, among the following:

- Never
- 1-3 times per year
- 4-10 times per year
- 10+ times per year

Question 7 *How much are you aware of the relevance of air traffic-related environmental impacts ranging from the effects of climate change and on air quality caused by aircraft emissions to noise pollution caused by aircraft engines? Rate your awareness on a scale from 1 to 5.*
This question relates to *Question 5*, spotlighting, more specifically, the respondents' awareness of air traffic's environmental impacts.

Question 8 *Which share of global energy-related CO_2 emissions do you believe air travel is accountable for?*

- around 10%
- around 21%
- around 7%

- around 2%
- less than 2%

Question 9 *How much relevance do you attribute to each of these material issues in the environmental context of air traffic impact? Rate each matter from 1 to 5.*

A. Impact on climate change

B. Air quality

C. Noise emission

Question 9 requires respondents to rate from 1 to 5 the importance they attribute to each material sustainability issue concerning air traffic to see how much consideration they attribute to each issue.

Question 10

Part A. Low price difference, same airline *Suppose you are booking your summer holidays to Dubai and purchasing your flight tickets. You are being offered two ticket alternatives from airline company A; ticket 1 consists of one round-trip ticket from Venice Marco Polo Airport to Dubai International Airport at EUR 600, including a surplus fee for offsetting carbon emissions. In contrast, ticket 2 consists of one round-trip ticket from Venice Marco Polo Airport to Dubai International Airport at EUR 590, without any additional fee, thus without offsetting carbon emissions.*
According to your sustainability preferences, which ticket would you choose to purchase?

- Ticket 1
- Ticker 2

Part B. High price difference, two different airlines *Suppose you decide to choose a different destination for your holidays vacation and to stay within your country, then you have to take a domestic flight. You are being proposed two alternatives by two different airline companies; Airline company A offers you ticket 1 at EUR 140, comprehensive of a fee offsetting carbon emissions; instead, Airline company B offers you ticket 2 at EUR 105, without the fee offsetting carbon emissions.*
According to your sustainability preferences, which ticket would you choose to purchase?

- Ticket 1 from Airline company A

- Ticker 2 from Airline company B

Question 11 *What are your beliefs concerning the credibility and the effectiveness of sustainability practices employed by airlines aimed at reducing flights' environmental impact?*
Answers obtained from this question permit us to understand how much respondents value airlines' efforts and strategies toward sustainability and how much sustainability commitment is worth and credible to them.
Respondents can select up to one answer between different alternatives.

- I do not honestly believe in such a climate emergency; companies embrace sustainability only for profit purposes, not because they genuinely care about the environment.
- I am aware of climate concerns and recognize the emergency and urgent action needed to curb emissions and environmental impacts to save the planet; however, many companies embrace sustainability only for profit purposes, generating greenwashing, not because they genuinely care about the environment.
- I am aware of climate concerns and recognize the emergency and urgent action needed to curb emissions and environmental impacts to save the planet; through accountability disclosure, many companies sincerely demonstrate their devotion to sustainability and their interest in preserving the environment, promoting sustainable development in all sustainability dimensions.

Question 12 *Which of these strategies do you believe are most effective in improving airlines' sustainability efforts?*
Based on their knowledge and preferences, respondents are asked to select one strategy that they believe could be the best at efficiently reducing air transport climate impact and improving the sustainability performance of airlines and, thus, their corporate reputation.

- Mandatory carbon offsetting programs (e.g., EU Emission Trading System, CORSIA scheme)
- Voluntary carbon offsetting programs (e.g., "green" fares)
- Operational enhancements and infrastructure improvements (e.g., Light-weight aircraft cabin equipment, reduced engine taxiing, different flight routes to curb emissions)
- Technological innovation (e.g., new aircraft engines, producing less noise and consuming less fuel; future production of hybrid and electric aircraft; new aircraft manufactured with lighter materials)

- Sustainable Aviation Fuel (SAF)
- Sustainable cabin practices (e.g., cabin waste recycling, promoting circular economy)

References

Abdullah, M.-A., Chew, B.-C., & Hamid, S.-R. (2016). Benchmarking key success factors for the future green airline industry. *Procedia-Social and Behavioral Sciences*, *224*, 246–253.

Agarwal, R. K. (2009). *Sustainable (green) aviation: Challenges and opportunities.* SAE International Warrendale, PA, USA.

Airbus. (2022). *A320neo — creating higher customer value.* Retrieved 2024, from https://aircraft.airbus.com/en/aircraft/a320-the-most-successful-aircraft-family-ever/a320neo-creating-higher-customer-value

Airbus. (2024). *Orders and deliveries.* Retrieved 2024, from https://www.airbus.com/en/products-services/commercial-aircraft/market/orders-and-deliveries

Akter, S., Brouwer, R., Brander, L., & Van Beukering, P. (2009). Respondent uncertainty in a contingent market for carbon offsets. *Ecological Economics*, *68*(6), 1858–1863.

Alameeri, A., Ajmal, M. M., Hussain, M., & Helo, P. T. (2017). Sustainability practices in the aviation sector: a study of uae-based airlines. *International Journal of Sustainable Society*, *9*(2), 119–147.

AlgarveDailyNews. (2022). *Ryanari helps reduce carbon footprint by planting another 75,000 trees in serra de monchique.* Retrieved 2024, from https://algarvedailynews.com/news/21152-ryanair-helps-reduce-carbon-footprint-by-planting-another-75-000-trees-in-serra-de-monchique

Anger, A., & Köhler, J. (2010). Including aviation emissions in the eu ets: Much ado about nothing? a review. *Transport Policy*, *17*(1), 38–46.

ATAG. (2020). *Environment and climate impacts of aviation continue growing.* Retrieved 2024, from https://aviationbenefits.org/un-sustainable-development-goals/

ATAG. (2021). *Waypoint 2050 report, 2nd edition: September 2021.* Retrieved 2024, from https://aviationbenefits.org/media/167417/w2050_v2021_27sept_full.pdf

ATAG. (2023a). *Environment and climate impacts of aviation continue growing.* Retrieved 2024, from https://aviationbenefits.org/environmental-efficiency/aviations-impact-on-the-environment/

ATAG. (2023b). *Net zero 2050: offsetting and carbon capture - fact sheet.* Retrieved 2024, from https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet---offsetting-and-carbon-capture/

ATAG. (2023c). *Supporting economic and social development.* Retrieved 2024, from https://atag.org/industry-topics/supporting-economic-social-development

Bai, M., Yang, W., Song, D., Kosuda, M., Szabo, S., Lipovsky, P., & Kasaei, A. (2020). Research on energy management of hybrid unmanned aerial vehicles to improve energy-saving and emission reduction performance. *International Journal of Environmental Research and Public Health*, *17*(8), 2917.

Barrett, S. R., Britter, R. E., & Waitz, I. A. (2010). Global mortality attributable to aircraft cruise emissions. *Environmental science & technology*, *44*(19), 7736–7742.

Bartels, L. (2012). The wto legality of the application of the eu's emission trading system to aviation. *European Journal of international law*, *23*(2), 429–467.

Becken, S., & Mackey, B. (2017). What role for offsetting aviation greenhouse gas emissions in a deep-cut carbon world? *Journal of Air Transport Management*, *63*, 71–83.

Boeing. (2016). *The 787 dreamliner family.* Retrieved 2024, from `https://www.boeing.com/commercial/787/by-design`

Boon, B., Davidson, M., Faber, J., & Van Velzen, A. (2007). Allocation of allowances for aviation in the eu ets. *CE Delft, Delft, The Netherlands*.

CAA. (2017). *Information on aviation's environmental impact, cap 1524.* Retrieved 2024, from `https://www.caa.co.uk/publication/download/15984`

Canadell, J., Monteiro, P., Costa, M., Cotrim da Cunha, L., Cox, P., Eliseev, A., ... Zickfeld, K. (2021). Global carbon and other biogeochemical cycles and feedbacks [Book Section]. In V. Masson-Delmotte et al. (Eds.), *Climate change 2021: The physical science basis. contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change* (p. 673–816). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. doi: 10.1017/9781009157896.007

Cazzola, P., & Lassman, J. (2021). Decarbonising air transport: acting now for the future.

Choi, A. S., Ritchie, B. W., & Fielding, K. S. (2016). A mediation model of air travelers' voluntary climate action. *Journal of Travel Research*, *55*(6), 709–723.

Clarke, D., Flachenecker, F., Guidetti, E., & Pionnier, P.-A. (2022). Co2 emissions from air transport: A near-real-time global database for policy analysis.

CMW. (2017). *Background briefing: Aviation under the eu emissions trading system (eu ets).* Retrieved 2024, from `https://carbonmarketwatch.org/wp-content/uploads/2017/02/FAQs-EU-ETS-and-aviation.pdf`

Colmer, J., Martin, R., Muûls, M., & Wagner, U. J. (2023). Does pricing carbon mitigate climate change? firm-level evidence from the european union emissions trading scheme.

Davies, N. (2007). The inconvenient truth about the carbon offset industry. *The Guardian*.

Delft, C., et al. (2019). Taxes in the field of aviation and their impact. *Final Report*, 1–150.

Dhanani, R. (2022). *A brief history of sustainability.* Retrieved 2024, from `https://thesustainableagency.com/blog/the-history-of-sustainability/`

EASA. (2022a). *Air quality, aviation and air pollution.* Retrieved 2024, from https://www.easa.europa.eu/eco/eaer/topics/adapting-changing-climate/air-quality

EASA. (2022b). *Impact of aircraft noise.* Retrieved 2024, from https://www.easa.europa.eu/eco/eaer/topics/adapting-changing-climate/noise

easyJet. (2023). *easyjet plc annual report and accounts 2023.* Retrieved 2024, from https://corporate.easyjet.com/files/doc_financials/2023/ar/43627_easyJet_Annual-Report_Web.pdf

easyJet. (2024). *What we do.* Retrieved 2024, from https://corporate.easyjet.com/about/what-we-do/default.aspx

EC. (2003). *Directive 2003/87/ec of the european parliament and of the council of 13 october 2003 establishing a scheme for greenhouse gas emission allowance trading within the community and amending council directive 96/61/ec.* Retrieved 2024, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32003L0087

EC. (2008). *Directive 2008/50/ec of the european parliament and of the council of 21 may 2008 on ambient air quality and cleaner air for europe.* Retrieved 2024, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0050

EC. (2019). *The european green deal - striving to be the first climate-neutral continent.* Retrieved 2024, from https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal

EC. (2020a). *Commission staff working document full-length report accompanying the document report from the commission to the european parliament and the council updated analysis of the non-co2 climate impacts of aviation and potential policy measures pursuant to eu emissions trading system directive article 30(4).* Retrieved 2024, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0277

EC. (2020b). *The european commission requested that the european union aviation safety agency (easa) conduct an updated analysis of the non-co2 effects of aviation on climate change to fulfil the requirement of the eu emissions trading system directive (art. 30.4).* Retrieved 2024, from https://climate.ec.europa.eu/news-your-voice/news/updated-analysis-non-co2-effects-aviation-2020-11-24_en

EC. (2020c). *Regulation (eu) 2020/852 of the european parliament and of the council of 18 june 2020 on the establishment of a framework to facilitate sustainable investment, and amending regulation (eu) 2019/2088.* Retrieved 2024, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0852

EC. (2020d). *Renewed sustainable finance strategy and implementation of the action plan on financing sustainable growth.* Retrieved 2024, from https://finance.ec.europa.eu/

publications/renewed-sustainable-finance-strategy-and-implementation-action-plan-financing-sustainable-growth_en

EC. (2021a). *Commission delegated regulation (eu) 2021/2139 of 4 june 2021 supplementing regulation (eu) 2020/852 of the european parliament and of the council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives.* Retrieved 2024, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2139

EC. (2021b). *Commission delegated regulation (eu) 2021/2178 of 6 july 2021 supplementing regulation (eu) 2020/852 of the european parliament and of the council by specifying the content and presentation of information to be disclosed by undertakings subject to articles 19a or 29a of directive 2013/34/eu concerning environmentally sustainable economic activities, and specifying the methodology to comply with that disclosure obligation.* Retrieved 2024, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2178

EC. (2023). *Commission delegated regulation (eu) 2023/2485 of 27 june 2023 amending delegated regulation (eu) 2021/2139 establishing additional technical screening criteria for determining the conditions under which certain economic activities qualify as contributing substantially to climate change mitigation or climate change adaptation and for determining whether those activities cause no significant harm to any of the other environmental objectives.* Retrieved 2024, from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302485&qid=1713796340996

EC. (2024a). *Aircraft noise.* Retrieved 2024, from https://transport.ec.europa.eu/transport-modes/air/environment/aircraft-noise_en?prefLang=it

EC. (2024b). *What is the eu ets?* Retrieved 2024, from https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/what-eu-ets_en

ECF. (2021). *Aviation sector and ngos agree on sustainability of future fuels.* Retrieved 2024, from https://europeanclimate.org/resources/aviation-sector-and-ngos-join-forces-on-sustainability-of-future-fuels/

EEA. (2019). *Environment and climate impacts of aviation continue growing.* Retrieved 2024, from https://www.eea.europa.eu/highlights/environment-and-climate-impacts-of

EESI. (2022). *Issue brief — the growth in greenhouse gas emissions from commercial aviation (2019, revised 2022).* Retrieved 2024, from https://www.eesi.org/papers/view/fact-sheet-the-growth-in-greenhouse-gas-emissions-from-commercial

-aviation

Elliff, M. T., Cremaschi, M. M., & Huck, M. V. (2020). *Impact of aircraft noise pollution on residents of large cities.* Retrieved 2024, from https://www.europarl.europa.eu/RegData/etudes/STUD/2020/650787/IPOL_STU(2020)650787_EN.pdf

EOD. (2024). *Earth overshoot day.* Retrieved 2024, from https://overshoot.footprintnetwork.org/

EP. (2023). *Air transport: Single european sky.* Retrieved 2024, from https://www.europarl.europa.eu/factsheets/en/sheet/133/air-transport-single-europeansky

Ernst, Y. (2007). Analysis of the ec proposal to include aviation activities in the emissions trading scheme (with york aviation). *Executive summary. New York: Ernst & Young.*

Eslaminassab, A., & Ehmer, H. (2021). Nudging air travellers towards carbon offsetting: The impact of an opt-out default on the offsetting rate. *Transportation Research Procedia*, *59*, 271–280.

Esposito, M., Tse, T., & Soufani, K. (2018). Introducing a circular economy: New thinking with new managerial and policy implications. *California Management Review*, *60*(3), 5–19.

EU. (2024). *Allocation to the aviation sector.* Retrieved 2024, from https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/free-allocation/allocation-aviation-sector_en

FAA. (2005). *Aviation & emissions, a primer.* Retrieved 2024, from https://catsr.vse.gmu.edu/SYST460/AviationEnv_PrimerFAA.pdf

FAA. (2023). *Single european sky.* Retrieved 2024, from https://www.faa.gov/nextgen

Faq: What is the eu taxonomy article 8 delegated act and how will it work in practice? (2021). Retrieved 2024, from https://finance.ec.europa.eu/document/download/af6e560f-842c-4ea9-ba5f-ef4a97246f88_en?filename=sustainable-finance-taxonomy-article-8-faq_en.pdf

Felder, J. L., Brown, G. V., DaeKim, H., & Chu, J. (2011). *Turboelectric distributed propulsion in a hybrid wing body aircraft* (Tech. Rep.).

Ficca, A., Marulo, F., & Sollo, A. (2023). An open thinking for a vision on sustainable green aviation. *Progress in Aerospace Sciences*, *141*, 100928.

Fichert, F., Forsyth, P., & Niemeier, H.-M. (2020a). Air transport and the challenge of climate change–how aviation climate change policies work. In *Aviation and climate change* (pp. 47–78). Routledge.

Fichert, F., Forsyth, P., & Niemeier, H.-M. (2020b). *Aviation and climate change.* Routledge Abingdon.

Fink, L. (2020). Larry fink's 2020 letter to ceos: A fundamental reshaping of finance.

BlackRock, avail able at https://www. blackrock. com/us/individual/larry fink ceo letter (accessed 10th August, 2022).

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner production*, *114*, 11–32.

Ghosh, S., Matthews, B., Camur, M. C., Majumder, S. R., Yang, Z., Bhaduri, A., ... others (2024). Climate impact of contrails from an aircraft fleet-level perspective. In *Aiaa scitech 2024 forum* (p. 1369).

Giddings, B., Hopwood, B., & O'brien, G. (2002). Environment, economy and society: fitting them together into sustainable development. *Sustainable development*, *10*(4), 187–196.

Giddings, E., & Carrier, A. (2023). *Eu taxonomy regulation and aviation: A transition to sustainability.* Retrieved 2024, from https://www.nortonrosefulbright.com/en/knowledge/publications/cea3bbd9/eu-taxonomy-regulation-and-aviation-a-transition-to-sustainability

Grewe, V. (2020). Aviation emissions and climate impacts. In *Aviation and climate change* (pp. 4–15). Routledge.

Hemmings, B., Murphy, A., Earl, T., Ambel, C. C., Gilliam, L., Sihvonen, J., & Buffet, L. (2020). Roadmap to decarbonising aviation. In *Aviation and climate change* (pp. 145–180). Routledge.

Hildebrand, P., & Donilon, T. (2020). *Davos brief. black-rock investment institute.*

Hult, G. T. M., Mena, J. A., Gonzalez-Perez, M. A., Lagerström, K., & Hult, D. T. (2018). A ten country-company study of sustainability and product-market performance: Influences of doing good, warm glow, and price fairness. *Journal of Macromarketing*, *38*(3), 242–261.

IAOPA. (2024). *What is general aviation.* Retrieved 2024, from https://www.iaopa.eu/what-is-general-aviation

IATA. (2017). 2036 forecast reveals air passengers will nearly double to 7.8 billion. *International Air Transport Association*, *24*, 2017–1.

IATA. (2019). *The iata/wrap cabin waste handbook.* Retrieved 2024, from https://www.iata.org/contentassets/821b593dd8cd4f4aa33b63ab9e35368b/iata-cabin-waste-handbook.pdf

IATA. (2020). *What is saf?* Retrieved 2024, from https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-what-is-saf.pdf

IATA. (2021). *Single european sky.* Retrieved 2024, from https://www.iata.org/en/about/worldwide/europe/single-european-sky/

IATA. (2023a). *Developing sustainable aviation fuel (saf).* Retrieved 2024, from https://

www.iata.org/en/programs/environment/sustainable-aviation-fuels/
IATA. (2023b). *Fact sheet corsia - december 2023.* Retrieved 2024, from https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet---corsia/
IATA. (2023c). *Net zero 2050: operational and infrastructure improvements, fact sheet.* Retrieved 2024, from https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet-netzero-operations-infrastructure/
IATA. (2023d). *Net zero 2050: sustainable aviation fuels.* Retrieved 2024, from https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet---alternative-fuels/
IATA. (2024a). *Aviation carbon exchange.* Retrieved 2024, from https://www.iata.org/en/programs/environment/ace/
IATA. (2024b). *Reassessing single-use plastic products in the airline sector; a report on the opportunities and challenges of replacement.* Retrieved 2024, from https://www.iata.org/contentassets/821b593dd8cd4f4aa33b63ab9e35368b/reassessing-supp-in-the-airline-sector_260324_rm-2.pdf
ICAO. (2009). *: Civil aviation statistics — icao classification and definition, review of the classification and definitions used for civil aviation activities.* Retrieved 2024, from https://web.archive.org/web/20150209030308/http://www.icao.int/Meetings/STA10/Documents/Sta10_Wp007_en.pdf
ICAO. (2010). *Operation of aircraft, part i international commercial air transport - airplanes.* Retrieved 2024, from https://web.archive.org/web/20150112170423/http://www.verifavia.com/bases/ressource_pdf/299/icao-annex-6-part-i.pdf
ICAO. (2016). *The aviation system block upgrades, the framework for global harmonization.* Retrieved 2024, from https://www.icao.int/airnavigation/Documents/ASBU_2016-FINAL.pdf
ICAO. (2017). *Icao council adopts new co2 emissions standard for aircraft.* Retrieved 2024, from https://www.icao.int/newsroom/pages/icao-council-adopts-new-co2-emissions-standard-for-aircraft.aspx
ICAO. (2022). *Impacts of aviation nox emissions on air quality, health, and climate.* Retrieved 2024, from https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2022/ENVReport2022_Art18.pdf
ICAO. (2024). *Aviation system block upgrade (asbu) implementation monitoring report.* Retrieved 2024, from https://www.icao.int/EURNAT/Pages/Aviation-System-Block-Upgrade-(ASBU)-Implementation-Monitoring-Report-.aspx
IEA. (2023a). *Aviation.* Retrieved 2024, from https://www.iea.org/energy-system/transport/aviation

IEA. (2023b). *Iea - tracking aviation.* Retrieved 2024, from https://www.iea.org/energy-system/transport/aviation

IEA. (2023c). *A new era for ccus.* Retrieved 2024, from https://www.iea.org/reports/ccus-in-clean-energy-transitions/a-new-era-for-ccus

International civil aviation organization (icao), balanced approach to aircraft noise management. (2020). Retrieved 2024, from https://www.icao.int/environmental-protection/Pages/noise.aspx

Irfan, M., Hassan, M., & Hassan, N. (2018). Unravelling the fuzzy effect of economic, social and environmental sustainability on the corporate reputation of public-sector organizations: A case study of pakistan. *Sustainability*, *10*(3), 769.

ITF. (2021). *Itf transport outlook 2021.* Retrieved from https://www.oecd-ilibrary.org/content/publication/16826a30-en doi: https://doi.org/https://doi.org/10.1787/16826a30-en

Johnson, Z., Ashoori, M. T., & Lee, Y. J. (2018). Self-reporting csr activities: when your company harms, do you self-disclose? *Corporate Reputation Review*, *21*, 153–164.

Jonsdottir, H. R., Delaval, M., Leni, Z., Keller, A., Brem, B. T., Siegerist, F., ... others (2019). Non-volatile particle emissions from aircraft turbine engines at ground-idle induce oxidative stress in bronchial cells. *Communications biology*, *2*(1), 90.

Kantenbacher, J., Hanna, P., Cohen, S., Miller, G., & Scarles, C. (2018). Public attitudes about climate policy options for aviation. *Environmental Science & Policy*, *81*, 46–53.

Kapadia, Z. Z., Spracklen, D. V., Arnold, S. R., Borman, D. J., Mann, G. W., Pringle, K. J., ... others (2016). Impacts of aviation fuel sulfur content on climate and human health. *Atmospheric Chemistry and Physics*, *16*(16), 10521–10541.

Kärcher, B. (2016). The importance of contrail ice formation for mitigating the climate impact of aviation. *Journal of Geophysical Research: Atmospheres*, *121*(7), 3497–3505.

Kim, S. (2019). The process model of corporate social responsibility (csr) communication: Csr communication and its relationship with consumers' csr knowledge, trust, and corporate reputation perception. *Journal of business ethics*, *154*(4), 1143–1159.

Kleymann, B., & Seristö, H. (2017). *Managing strategic airline alliances.* Routledge.

KLM. (2023). *Klm royal dutch airlines - annual report 2023.* Retrieved 2024, from https://www.klmannualreport.com/wp-content/uploads/2024/04/KLM-Annual-Report_2023.pdf

KLM. (2024a). *Co2 compensation by reforestation and/or sustainable aviation fuel (saf) conditions.* Retrieved 2024, from https://www.klm.it/en/information/legal/extra-options/co2-impact-programme

KLM. (2024b). *Klm company profile.* Retrieved 2024, from https://www.klm.it/en/

information/corporate/company-profile

Klöwer, M., Allen, M., Lee, D., Proud, S., Gallagher, L., & Skowron, A. (2021). Quantifying aviation's contribution to global warming. *Environmental Research Letters*, *16*(10), 104027.

Knorr, A., & Eisenkopf, A. (2020). Voluntary carbon offset schemes in the airline industry: Why did they fail? In *Aviation and climate change* (pp. 130–144). Routledge.

Kucukvar, M., Alawi, K. A., Abdella, G. M., Bulak, M. E., Onat, N. C., Bulu, M., & Yalçıntaş, M. (2021). A frontier-based managerial approach for relative sustainability performance assessment of the world's airports. *Sustainable Development*, *29*(1), 89–107.

Lan, H. (2011). Comments on eu aviation ets directive and eu-china aviation emission dispute. *RJT ns*, *45*, 589.

Lee, D. S. (2018). The current state of scientific understanding of the non-co2 effects of aviation on climate. *UK Department for Transport, Manchester Metropolitan University*.

Lee, D. S., Allen, M. R., Cumpsty, N., Owen, B., Shine, K. P., & Skowron, A. (2023). Uncertainties in mitigating aviation non-co 2 emissions for climate and air quality using hydrocarbon fuels. *Environmental Science: Atmospheres*, *3*(12), 1693–1740.

Lee, D. S., Fahey, D. W., Skowron, A., Allen, M. R., Burkhardt, U., Chen, Q., ... others (2021). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric environment*, *244*, 117834.

Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., ... others (2023a). *Climate change 2023: synthesis report. contribution of working groups i, ii and iii to the sixth assessment report of the intergovernmental panel on climate change.* The Australian National University.

Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., ... others (2023b). Ipcc, 2023: Climate change 2023: Synthesis report, summary for policymakers. contribution of working groups i, ii and iii to the sixth assessment report of the intergovernmental panel on climate change [core writing team, h. lee and j. romero (eds.)]. ipcc, geneva, switzerland.

Lufthansa. (2022a). *Lufthansa group, report 2022 - sasb.* Retrieved 2024, from https://www.lufthansagroup.com/media/downloads/en/responsibility/LH-SASB-Report-2022.pdf

Lufthansa. (2022b). *Lufthansa group, report 2022 - tcfd.* Retrieved from https://www.lufthansagroup.com/media/downloads/en/responsibility/LH-TCFD-Report-2022.pdf

Lufthansa. (2022c). *Sustainability 2022 - factsheet.* Retrieved 2024, from https://www.lufthansagroup.com/media/downloads/en/responsibility/LH-Factsheet-Sustainability-2022.pdf

Lufthansa. (2023a). *Lufthansa group - annual report 2023.* Retrieved 2024, from https://investor-relations.lufthansagroup.com/fileadmin/downloads/en/financial-reports/annual-reports/LH-AR-2023-e.pdf#page=73

Lufthansa. (2023b). *Lufthansa group, report 2023 - sasb.* Retrieved 2024, from https://www.lufthansagroup.com/media/downloads/en/responsibility/LHG-SASB-Report-2023.pdf

Lufthansa. (2023c). *Lufthansa group, report 2023 - tcfd.* Retrieved 2024, from https://www.lufthansagroup.com/media/downloads/en/responsibility/LH-TCFD-Report-2023.pdf

Lufthansa. (2023d). *Sustainability 2023 - factsheet.* Retrieved 2024, from https://www.lufthansagroup.com/media/downloads/en/responsibility/LH-Factsheet-Sustainability-2023.pdf

Lufthansa. (2024a). *More sustainable flying.* Retrieved 2024, from https://www.lufthansagroup.com/en/responsibility/climate-environment/more-sustainable-flying.html

Lufthansa. (2024b). *Passenger airlines offers their customers a differentiated and high-quality product.* Retrieved 2024, from https://www.lufthansagroup.com/en/company/business-segments/passenger-airlines.html

Maertens, S., Grimme, W., & Scheelhaase, J. (2020). Icao's new corsia scheme at a glance–a milestone towards greener aviation? In *Aviation and climate change* (pp. 117–129). Routledge.

Masiol, M., & Harrison, R. M. (2014). Aircraft engine exhaust emissions and other airport-related contributions to ambient air pollution: A review. *Atmospheric Environment*, *95*, 409–455.

Matthes, S., Grewe, V., Dahlmann, K., Frömming, C., Irvine, E., Lim, L., ... others (2017). A concept for multi-criteria environmental assessment of aircraft trajectories. *Aerospace*, *4*(3), 42.

Melo, T., & Garrido-Morgado, A. (2012). Corporate reputation: A combination of social responsibility and industry. *Corporate social responsibility and environmental management*, *19*(1), 11–31.

Moldan, B., Janoušková, S., & Hák, T. (2012). How to understand and measure environmental sustainability: Indicators and targets. *Ecological indicators*, *17*, 4–13.

Morrell, P. (2020). Etss and aviation: Implementation of schemes in the eu and other countries. In *Aviation and climate change* (pp. 79–103). Routledge.

Penner, J. E., Lister, D., Griggs, D. J., Dokken, D. J., & McFarland, M. (1999). *Aviation and the global atmosphere: a special report of the intergovernmental panel on climate change*. Cambridge University Press.

Pitari, G., Iachetti, D., Di Genova, G., De Luca, N., Søvde, O. A., Hodnebrog, Ø., … Lim, L. L. (2015). Impact of coupled nox/aerosol aircraft emissions on ozone photochemistry and radiative forcing. *Atmosphere*, *6*(6), 751–782.

Questions and answers: political agreement on an eu-wide classification system for sustainable investments (taxonomy). (2019). Retrieved 2024, from https://ec.europa.eu/commission/presscorner/detail/it/qanda_19_6804

Ritchie, B. W., Kemperman, A., & Dolnicar, S. (2021). Which types of product attributes lead to aviation voluntary carbon offsetting among air passengers? *Tourism Management*, *85*, 104276.

Ritchie, H. (2024). What share of global co_2 emissions come from aviation? *Our World in Data*. (https://ourworldindata.org/global-aviation-emissions)

Robinson, W. C. (1973). *The limits to growth: A report for the club of rome's project on the predicament of mankind.* JSTOR.

Rogers, P. P., Jalal, K. F., & Boyd, J. A. (2012). *An introduction to sustainable development.* Routledge.

Ropret Homar, A., & Knežević Cvelbar, L. (2024). Combatting climate change through message framing? a real behavior experiment on voluntary carbon offsetting. *Journal of Travel Research*, *63*(4), 883–903.

Rotaris, L., Giansoldati, M., & Scorrano, M. (2020). Are air travellers willing to pay for reducing or offsetting carbon emissions? evidence from italy. *Transportation Research Part A: Policy and Practice*, *142*, 71–84.

Ryanair. (2023). *Sustainability report 2023.* Retrieved 2024, from https://corporate.ryanair.com/wp-content/uploads/2023/07/Ryanair-2023-Sustainability-Report.pdf

Ryanair. (2024). *About us, our network.* Retrieved 2024, from https://corporate.ryanair.com/about-us/our-network/

Salesa, A., León, R., & Moneva, J. M. (2023). Airlines practices to incorporate circular economy principles into the waste management system. *Corporate Social Responsibility and Environmental Management*, *30*(1), 443–458.

Schumann, U. (2002). Aircraft emissions. *Encyclopedia of global environmental change*, *3*, 178–186.

Segerstedt, A., & Grote, U. (2016). Increasing adoption of voluntary carbon offsets among tourists. *Journal of Sustainable Tourism*, *24*(11), 1541–1554.

Skowron, A., Lee, D. S., & De León, R. R. (2015). Variation of radiative forcings and global warming potentials from regional aviation nox emissions. *Atmospheric Environment*, *104*, 69–78.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K., ... others (2007). The physical science basis. *Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change*, *996*, 2007.

Sonnenschein, J., & Mundaca, L. (2019). Is one carbon price enough? assessing the effects of payment vehicle choice on willingness to pay in sweden. *Energy Research & Social Science*, *52*, 30–40.

Sonnenschein, J., & Smedby, N. (2019). Designing air ticket taxes for climate change mitigation: insights from a swedish valuation study. *Climate Policy*, *19*(5), 651–663.

Spindler, E. A. (2013). The history of sustainability the origins and effects of a popular concept. In *Sustainability in tourism: A multidisciplinary approach* (pp. 9–31). Springer.

UN. (2015). *National sustainable development strategies (nsds).* Retrieved 2024, from https://sustainabledevelopment.un.org/topics/nationalsustainabledevelopmentstrategies

UN. (2021). *What is climate change?* Retrieved 2024, from https://www.un.org/en/climatechange/what-is-climate-change

UN. (2024). *United nations, the 17 goals.* Retrieved 2024, from https://sdgs.un.org/goals

UNFCCC. (2007). *What is the kyoto protocol?* Retrieved 2024, from https://unfccc.int/kyoto_protocol

UNFCCC. (2024). *The paris agreement.* Retrieved 2024, from https://unfccc.int/process-and-meetings/the-paris-agreement

von der Leyen, U. (2019). *Press remarks by president von der leyen on the occasion of the adoption of the european green deal communication.* Retrieved 2024, from https://ec.europa.eu/commission/presscorner/detail/fr/speech_19_6749

Wang, Z., Huang, W., & Chen, Z. (2019). The peak of co2 emissions in china: a new approach using survival models. *Energy Economics*, *81*, 1099–1108.

Wey, C., & Lee, C.-M. (2017). Aircraft emissions: gaseous and particulate. *Green aviation: Reduction of environmental impact through aircraft technology and alternative fuels*, 48.

WWF. (1980). *World conservation strategy: Living resource conservation for sustainable development* (Vol. 1). Gland, Switzerland: IUCN.

Yim, S. H., Lee, G. L., Lee, I. H., Allroggen, F., Ashok, A., Caiazzo, F., ... Barrett, S. R. (2015). Global, regional and local health impacts of civil aviation emissions.

Environmental Research Letters, *10*(3), 034001.

Yohan Kim, J. L., Sunyoung Yun, & Ko, E. (2016). How consumer knowledge shapes green consumption: an empirical study on voluntary carbon offsetting. *International Journal of Advertising*, *35*(1), 23–41. Retrieved from `https://doi.org/10.1080/02650487.2015.1096102` doi: 10.1080/02650487.2015.1096102

Zhang, B., Ritchie, B., Mair, J., & Driml, S. (2019). Is the airline trustworthy? the impact of source credibility on voluntary carbon offsetting. *Journal of Travel Research*, *58*(5), 715–731.